Development of New Photosensors

Daniel Ferenc

Eckart Lorenz (became UCD faculty)

Daniel Kranich (Feodor Lynen Fellow)

Alvin Laille (Graduate Student)

University of California Davis

More motivated people would like to participate:

Vladimir Peskov (Stockholm), Glenn Knoll, postdocs from ~CERN

MOTIVATION:

Unique importance of Photosensors for

Next-Generation Projects in HE Physics and Astrophysics

Similar importance for Homeland Security

Work supported in part by the:

Advanced Detector Research Award

DOE/HEP, Mike Procario

"Novel Highly Sensitive Photosensor Technology for Inexpensive Large Area Cherenkov Detectors"

We applied for a new ADR grant for

"Light Amplifier"

Future projects aiming to study very rarely occurring phenomena

- <u>Proton decay, Neutrino Physics and Astrophysics</u>

  UNO, HYPER-K, Kilometer-Cube, also Nestor, Nemo, Antares, etc.

- <u>Gamma-ray Astronomy</u> – a study of faint and/or variable sources requires telescopes with

  low detection threshold <u>& wide acceptance angle</u>

- <u>Ultrahigh-energy cosmic rays</u> (>10^19 eV)

  Auger, EUSO, OWL,…

- <u>Double beta decay</u>

New Experiments need sensitivity for very rare phenomena

↓

Very Large Volumes/Areas

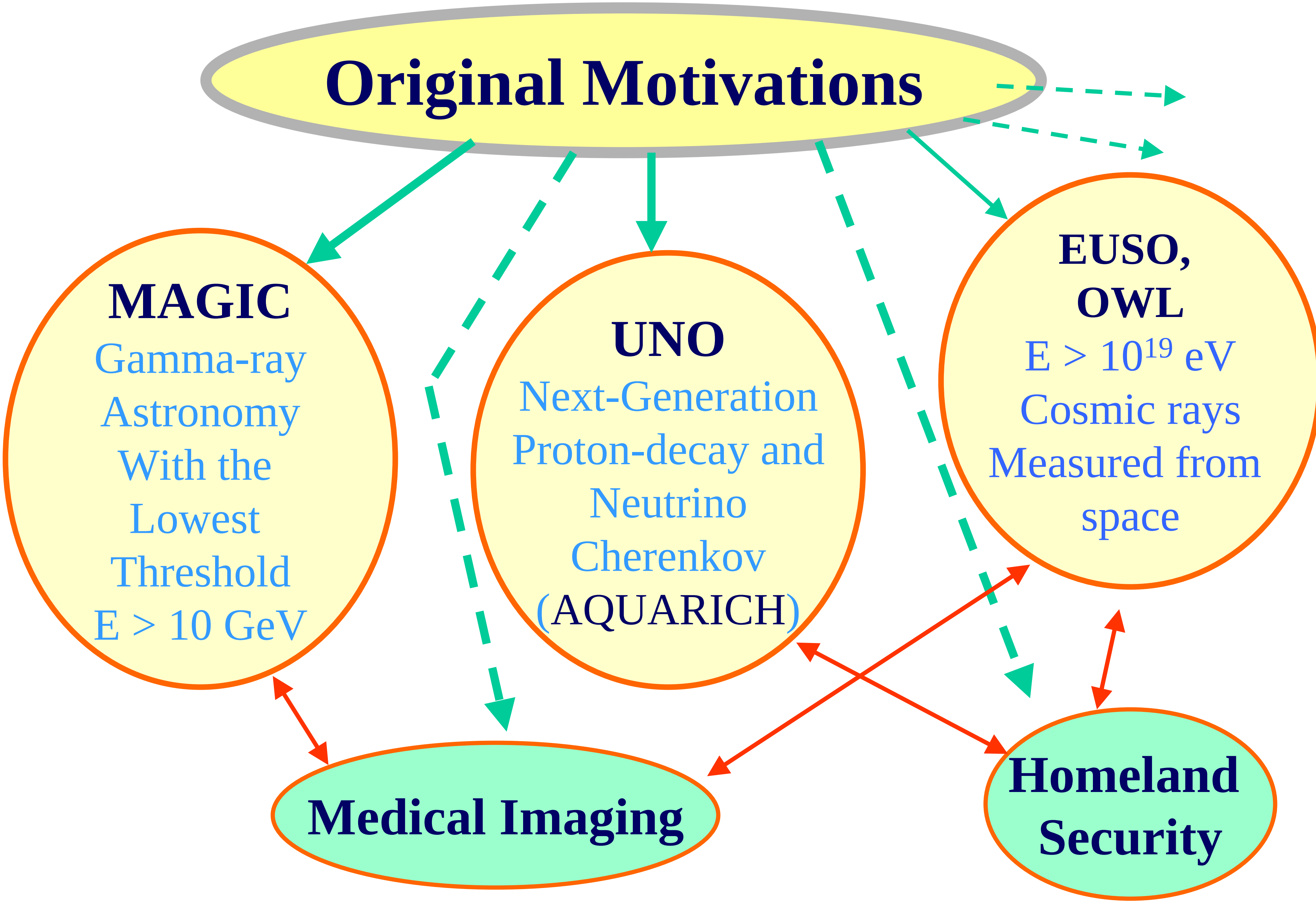
↓

No other choice than

"Natural" **Transparent** Media
(Water, Atmosphere, Ice)

↓

PHOTOSENSORS


Original Motivations
MAGIC
Gamma-ray Astronomy With the Lowest Threshold E > 10 GeV
UNO
Next-Generation Proton-decay and Neutrino Cherenkov (AQUARICH)
EUSO, OWL
E > 10^{19} eV Cosmic rays Measured from space
Medical Imaging
Homeland Security

Several unconventional photosensor concepts

- **Flat-Panel “*ReFerence*” Camera Concept (Patented)**
- **“*Light Amplifier*” concept, development just started**
- **“*SIMPLE*” Imaging Camera Concept, project idling, (Patent Pending)**
- **A New Concept – currently secret (patentable?)**

STATUS @ UC Davis

- ReFerence Prototypes – to be completed in 2004
- Photocathode Development (under way)
- "Light Amplifier" Development (just started)
- A "New Idea"
- **Equipment purchased recently (>$2M value)**

For Photocathode development:

Surface Science laboratory: AES, XPE, SIMS,…

For Flat Panel <u>manufacturing</u>:

2 Flat Panel Sealing Devices (IR Laser Sealing)

Several Transfer Systems !!!

Laser Sealing System (2)

Common Requirements

- High efficiency, high packing factor (low dead area)
- Low noise
- Fast response (~1 ns)
- Wide spectral coverage (Cherenkov)
- Single-photon sensitivity and resolution
- Color sensitivity
- Mass industrial production (e.g. no glass blowing), high quantity, high quality, short production cycle
- Low cost

Project-specific Requirements

Due to the Interplay of

Different light beaming conditions

(e.g. Cherenkov angle in medium)

&

Liouville's phase space law

1. Sensitive area covered by the "camera"

in general very-very LARGE,

but may also vary a lot: m^2 – km^2

2. Pixel size

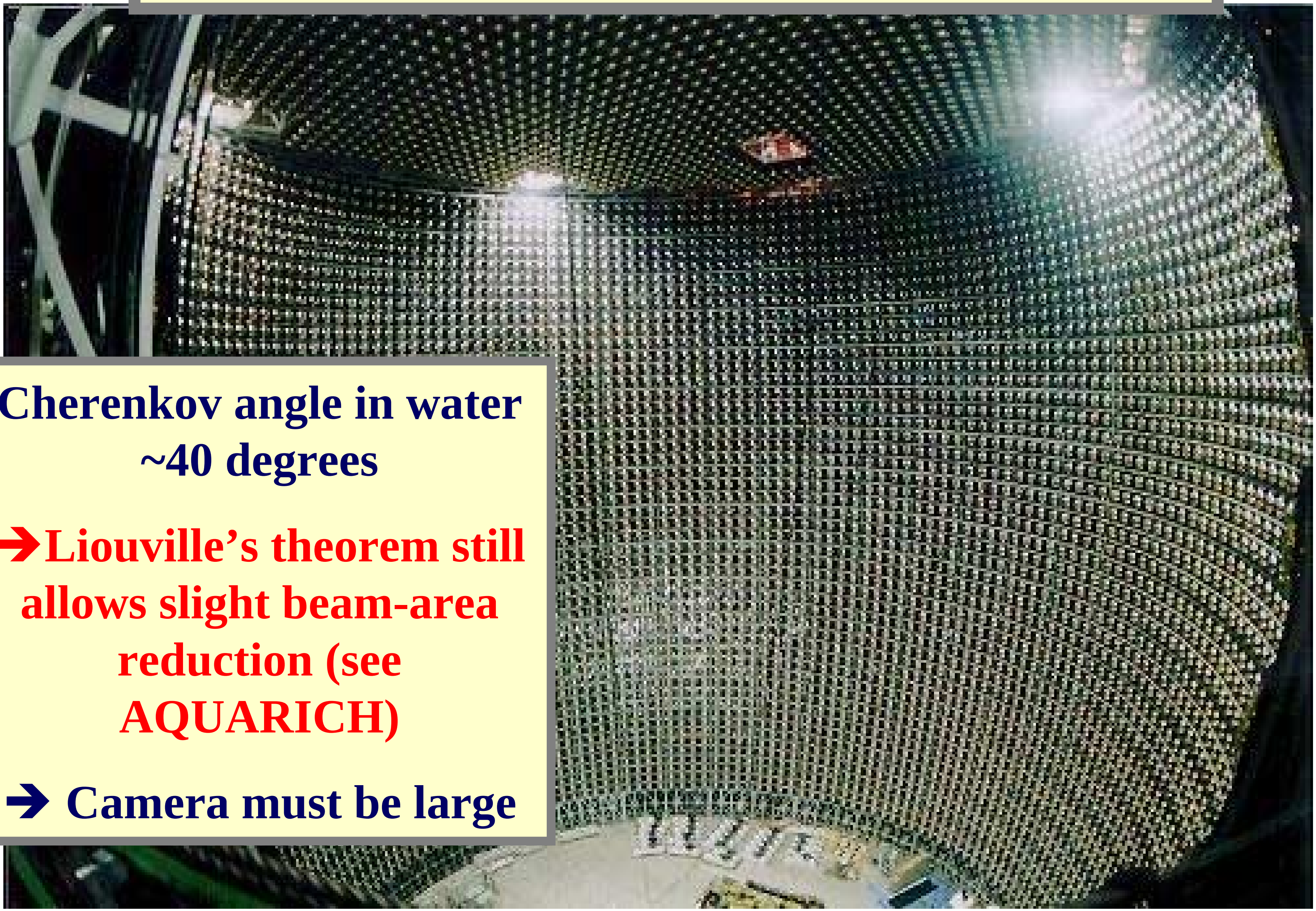
in general very LARGE,

but may vary: several mm – several 10 cm

→ Difficult to find a universal solution

(one needs a scallable concept)

SuperKamiokande



Cherenkov angle in water ~40 degrees

➔Liouville's theorem still allows slight beam-area reduction (see AQUARICH)

➔ Camera must be large

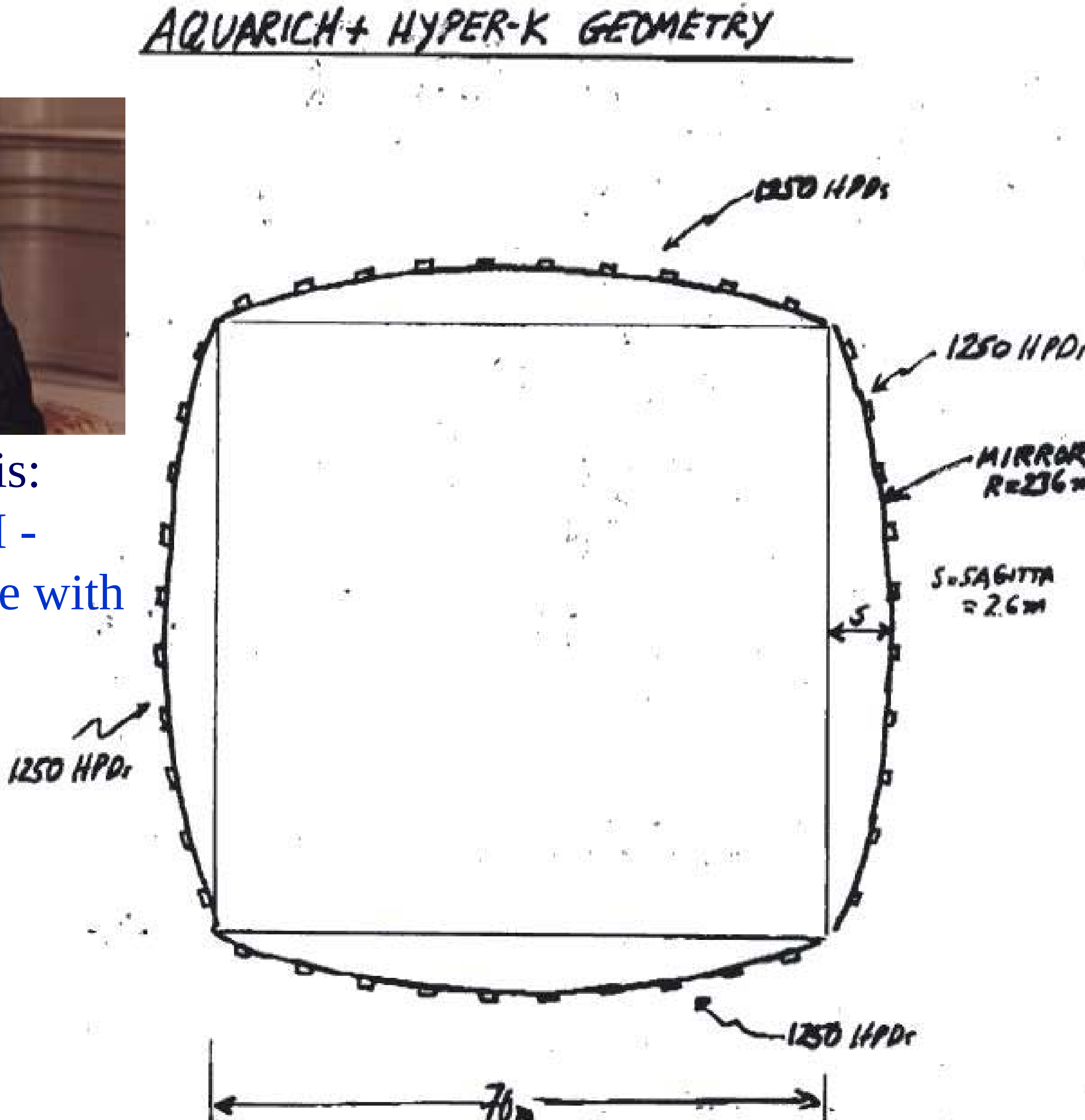
Cherenkov angle in air < 1 degree, also well defined observational direction, and small angular spread in the EM shower

➔ Liouville's theorem allows significant beam area reduction

➔ The Camera can have a small area

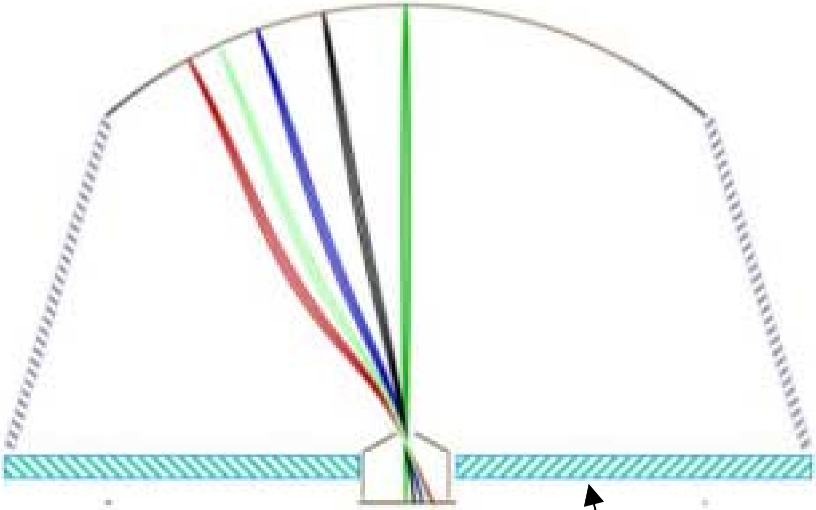
MAGIC Telescope Inauguration, October 10 2003. (Photo-W. Ko)

Tom Ypsilantis:
"AQUARICH -
Super Kamiokande with
Spectacles"



AQUARICH with Fresnel Lenses

"SIMPLE" camera



Tom Ypsilantis:
"AQUARICH -
Super Kamiokande with
Spectacles"

MIRROR → Fresnel Lens

Large (~2m) camera with Fresnel optics

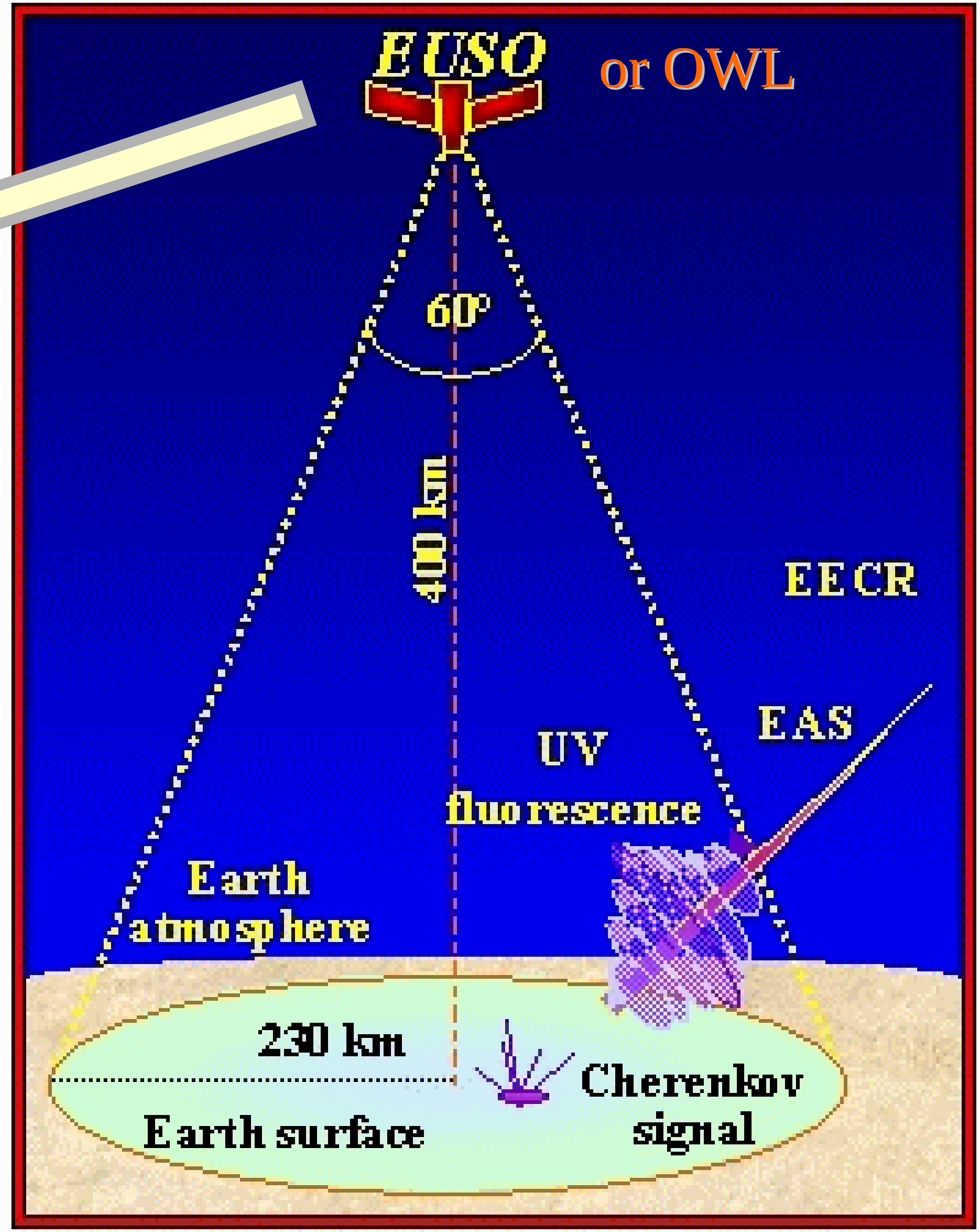
Fluorescence light

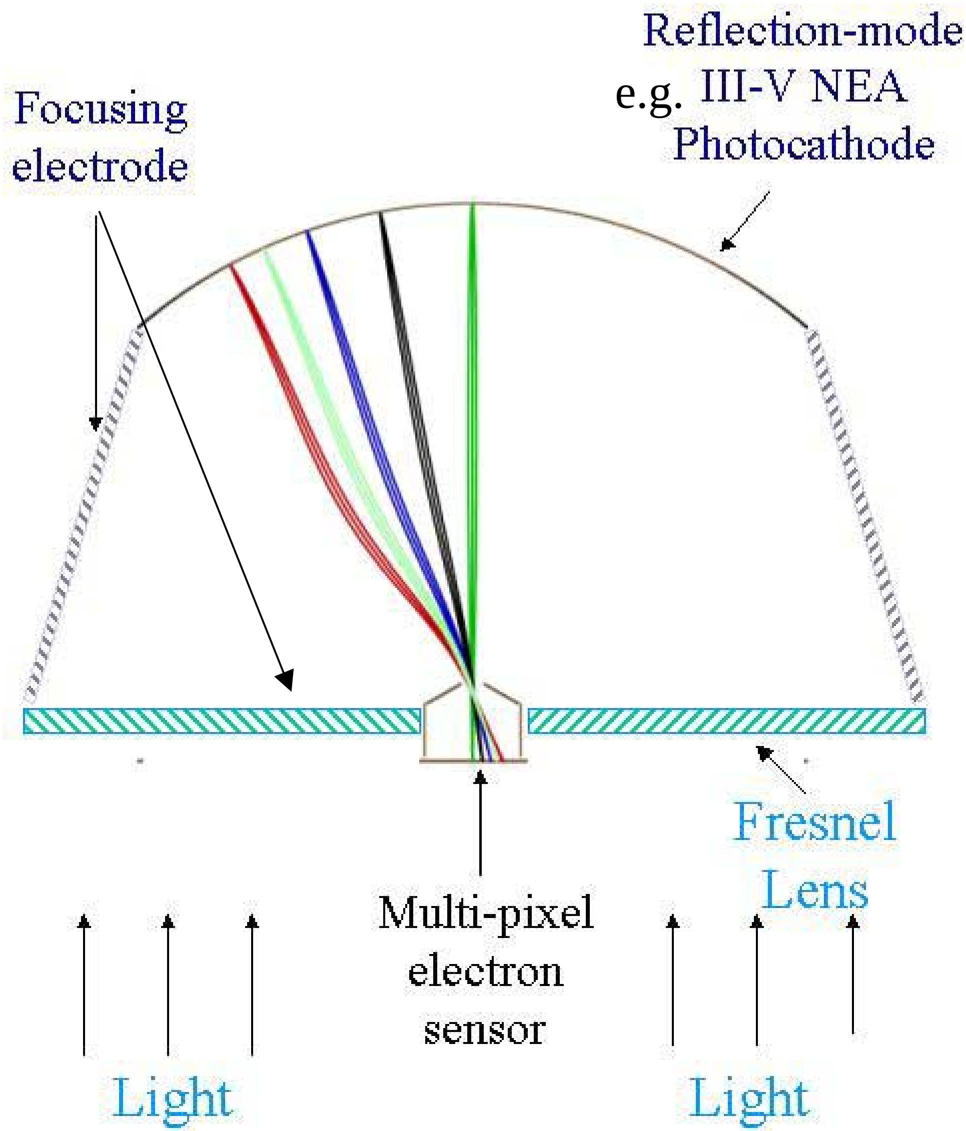
the angle in the atmosphere is 4-pi steradian

➔ Liouville's theorem allows NO beam-area reduction

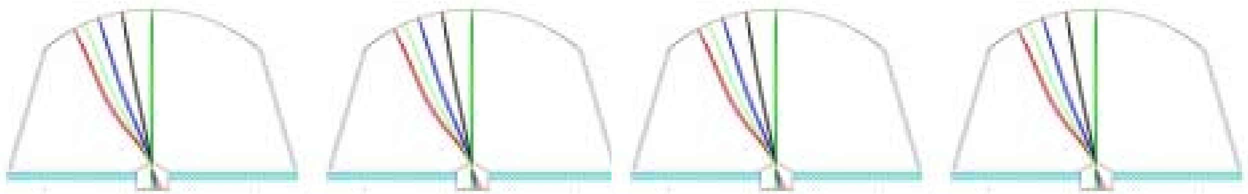
➔ But the camera may be small in

"classical imaging"

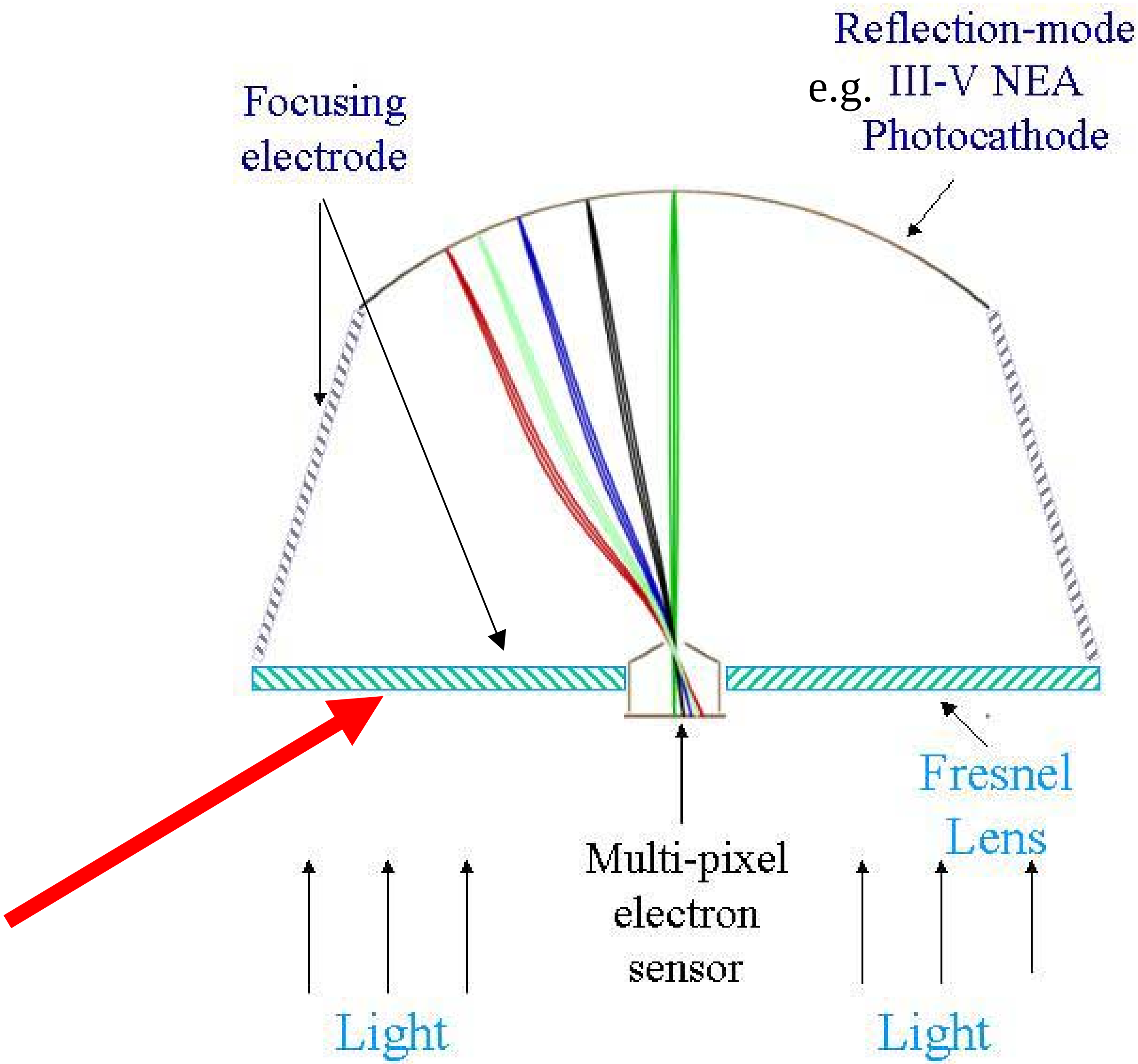




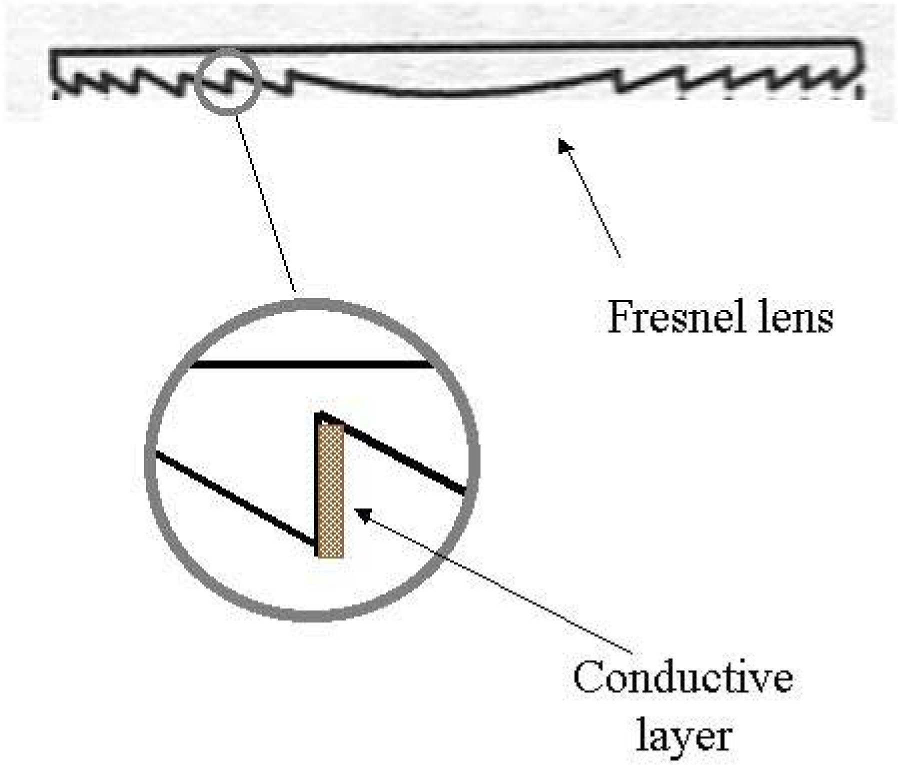
Focusing electrode
Reflection-mode
e.g. III-V NEA
Photocathode
Fresnel
Lens
Multi-pixel
electron
sensor
Light
Light



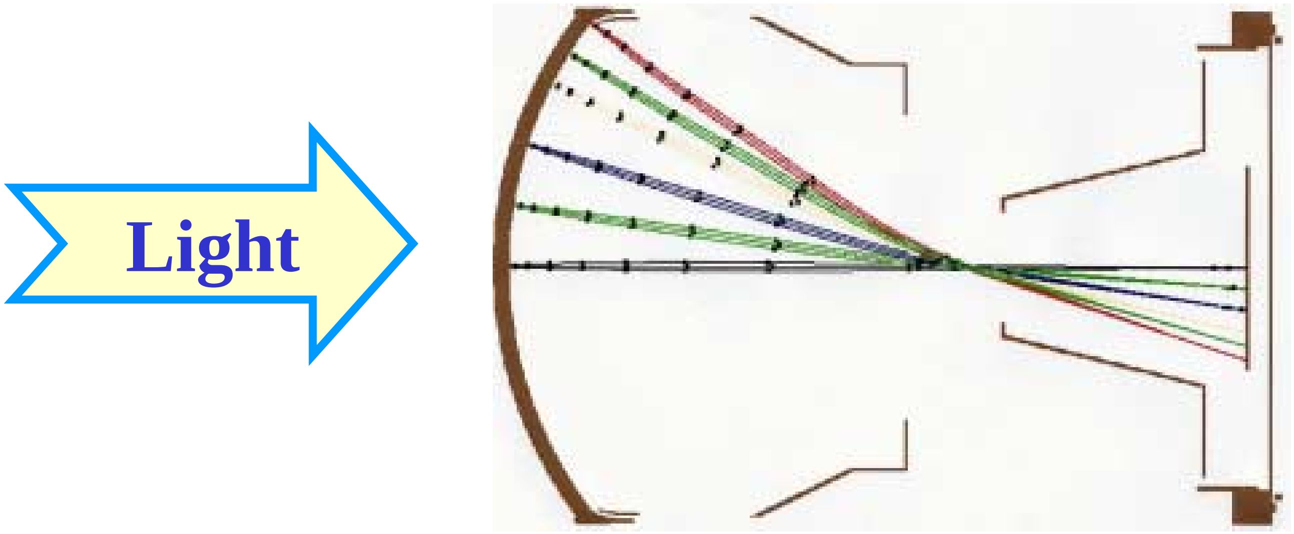
→ spin-off for ground-based applications


Reflection-mode
e.g. III-V NEA
Photocathode
Focusing
electrode
Fresnel
Lens
Multi-pixel
electron
sensor
Light
Light

Fresnel Lens → Electrode



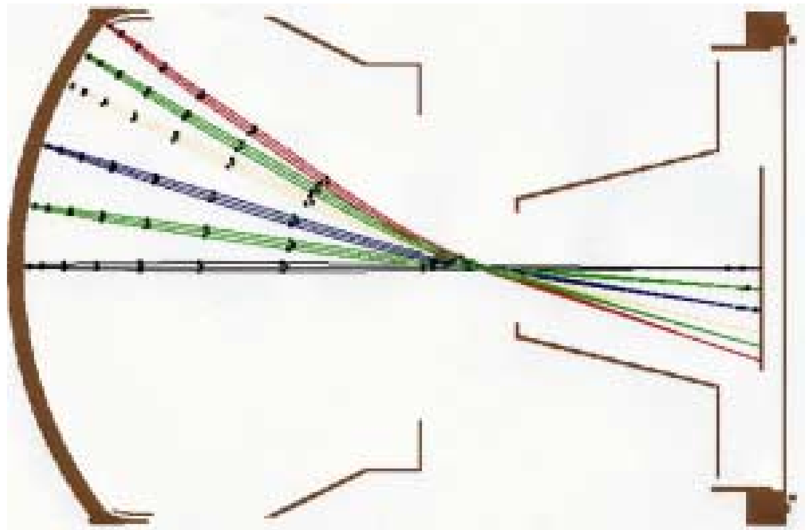
No additional obstruction for light,
even helps to absorb stray light



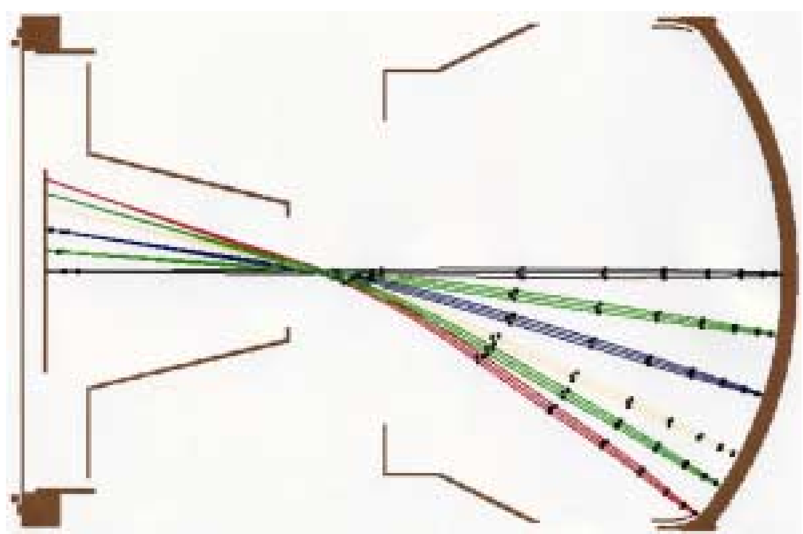
Designed for LHCb and AQUARICH (~1998)

D. Ferenc, **Imaging Hybrid Photon Detectors with Minimized Dead Area and Protection Against Positive Ion Feedback**. Nucl.Instrum.Meth. A431(1999)460-475.

Light



Light



Irreducibly Large

Illuminated Area

↓

Photosensors with

- **Very strong internal information concentration**

  → Vacuum

- **More efficient photocathodes**
- **Industrial Mass-Producible at very low cost**

OBJECTIVES

1. Large Photosensor Area Coverage

- High Quantity
- High Quality
- Low Price

➔ **Industrial Mass Production**

2. High Detection Efficiency and S/N

Semiconductor Photosensors

→ developed dramatically fast after ~ the WW-2

(but too small pixel size and area)

Vacuum Photosensors (suitable for large-area applications) did not develop significantly since mid-1960s

Why?

Because of Vacuum?

Development of Other Vacuum Devices

~1960

~2000

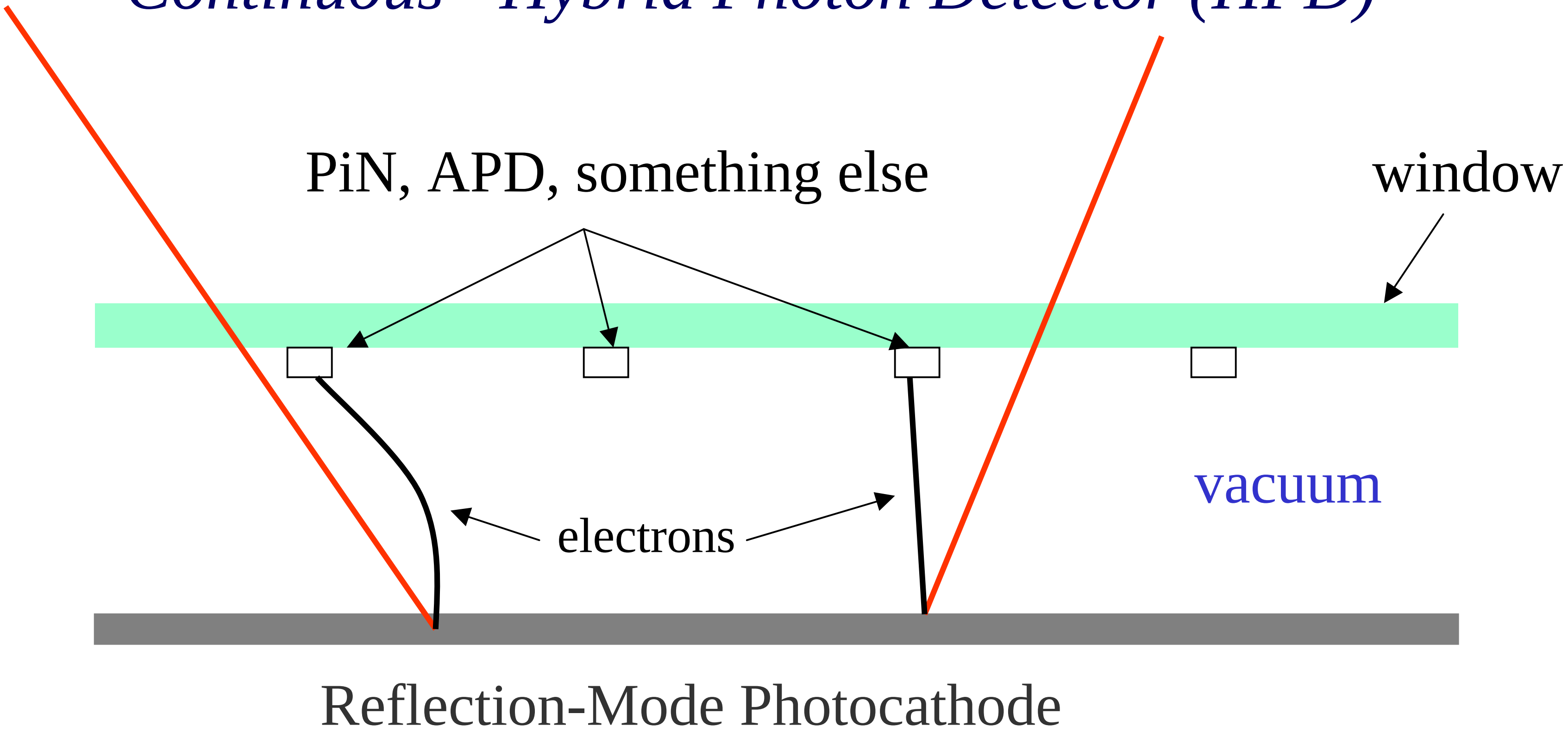
Flat-Panel <u>Camera</u> Configuration →

provided by the *ReFerence* Photosensor Concept

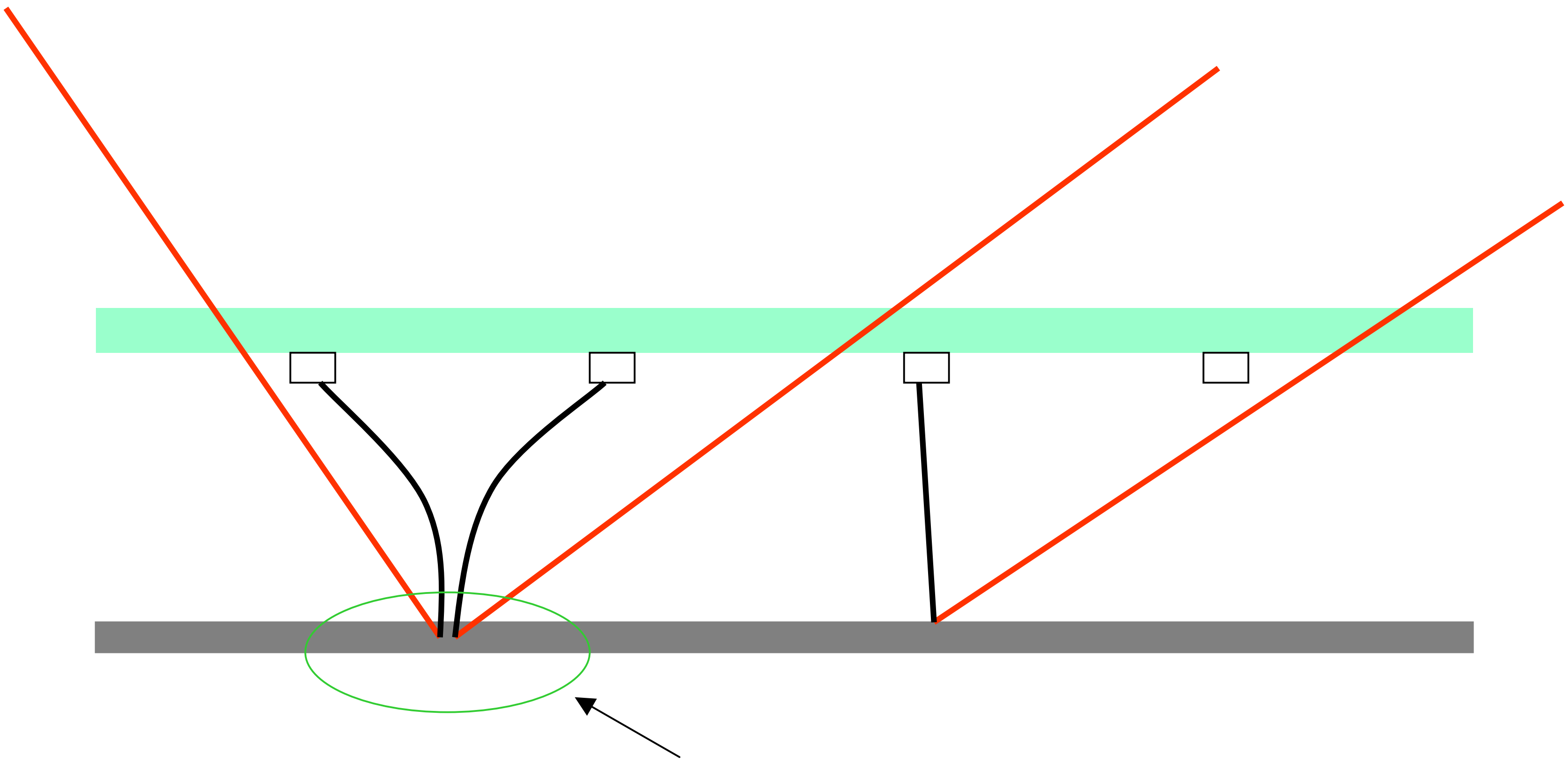
OUR GOAL

Flat Panel Camera – wishful thinking:

"Continuous" Hybrid Photon Detector (HPD)



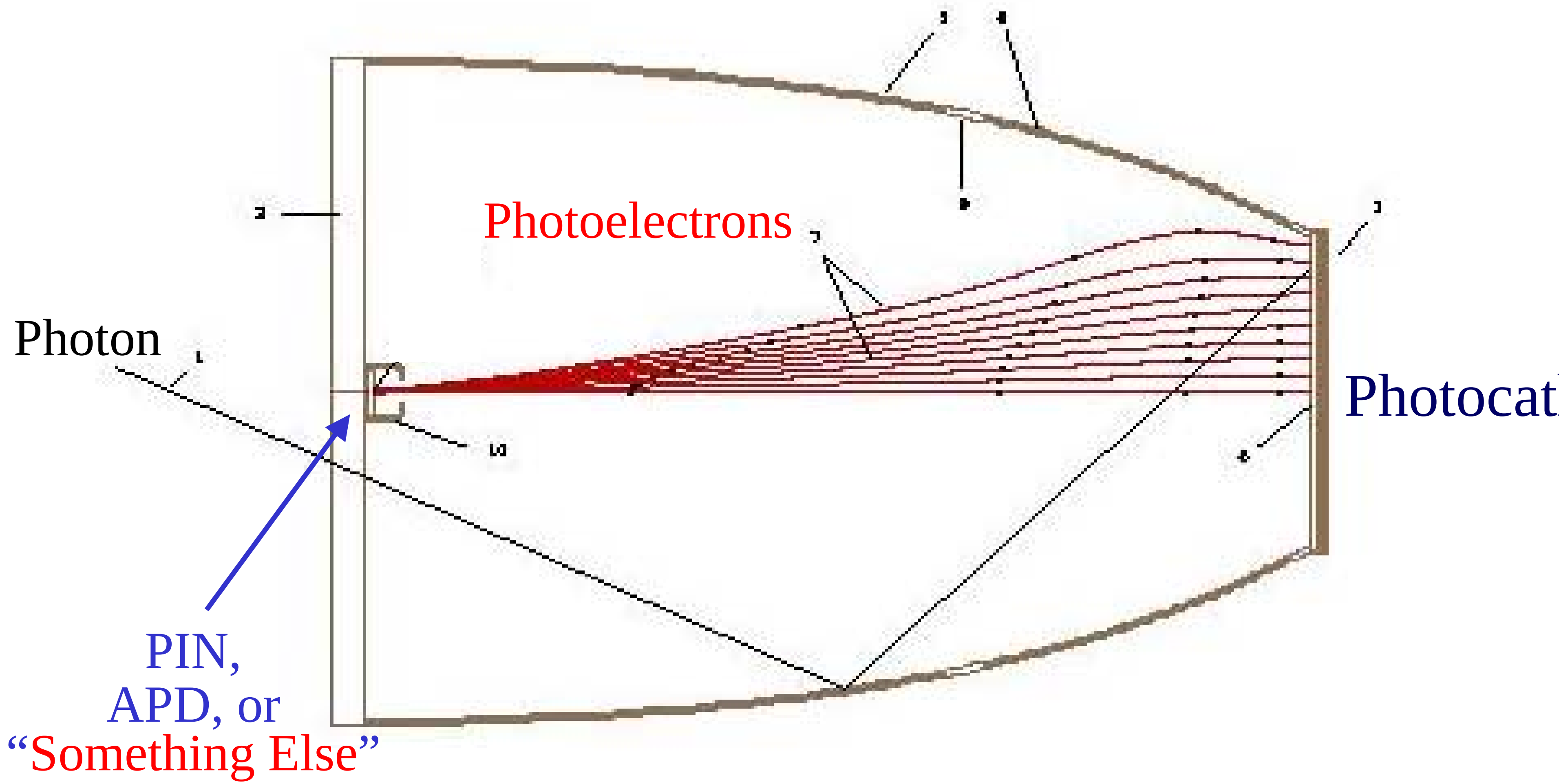
BUT:



This doesn’t work!

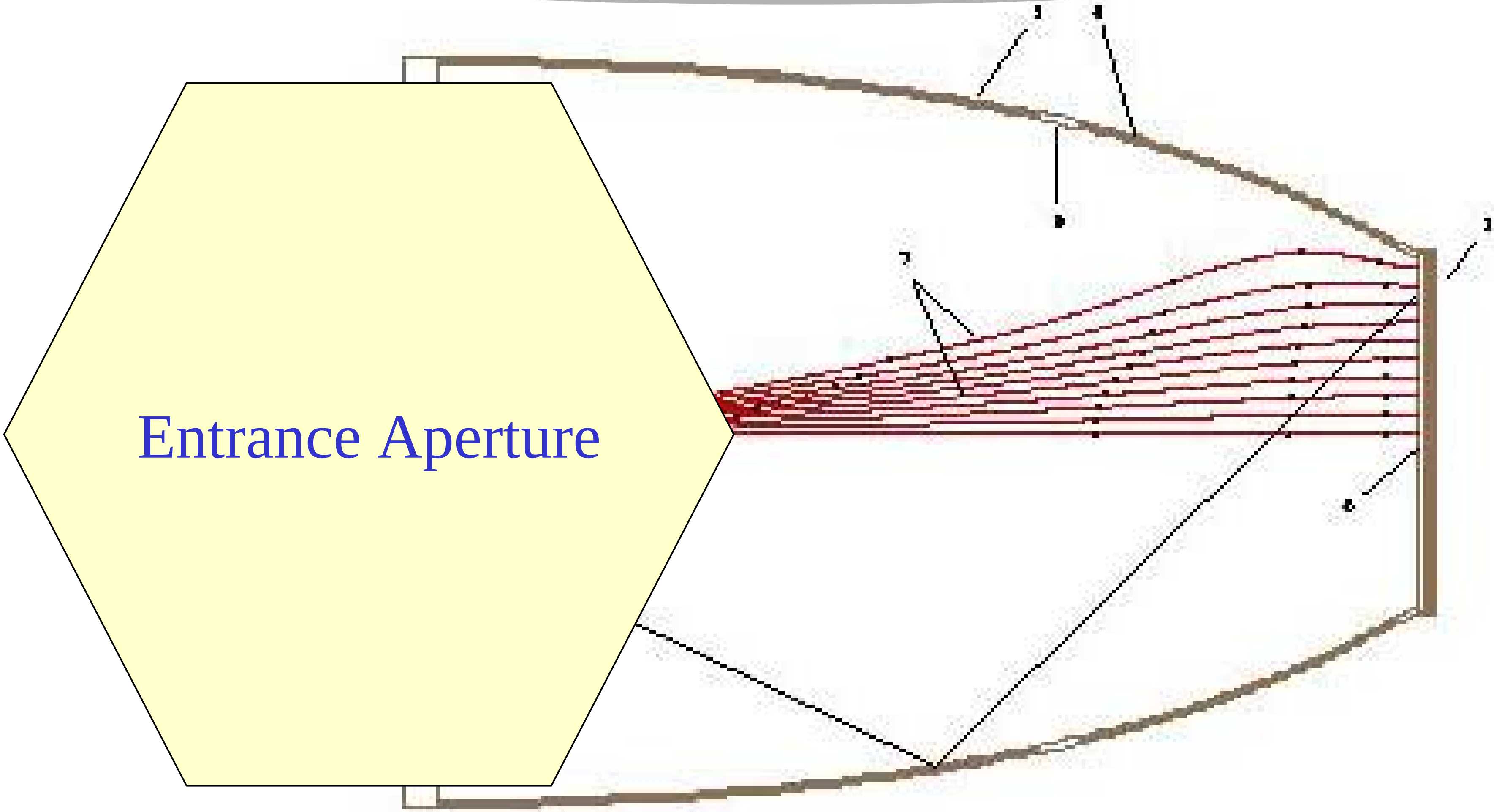
Ideal Light Concentrator

(takes the maximum of Liouville!)

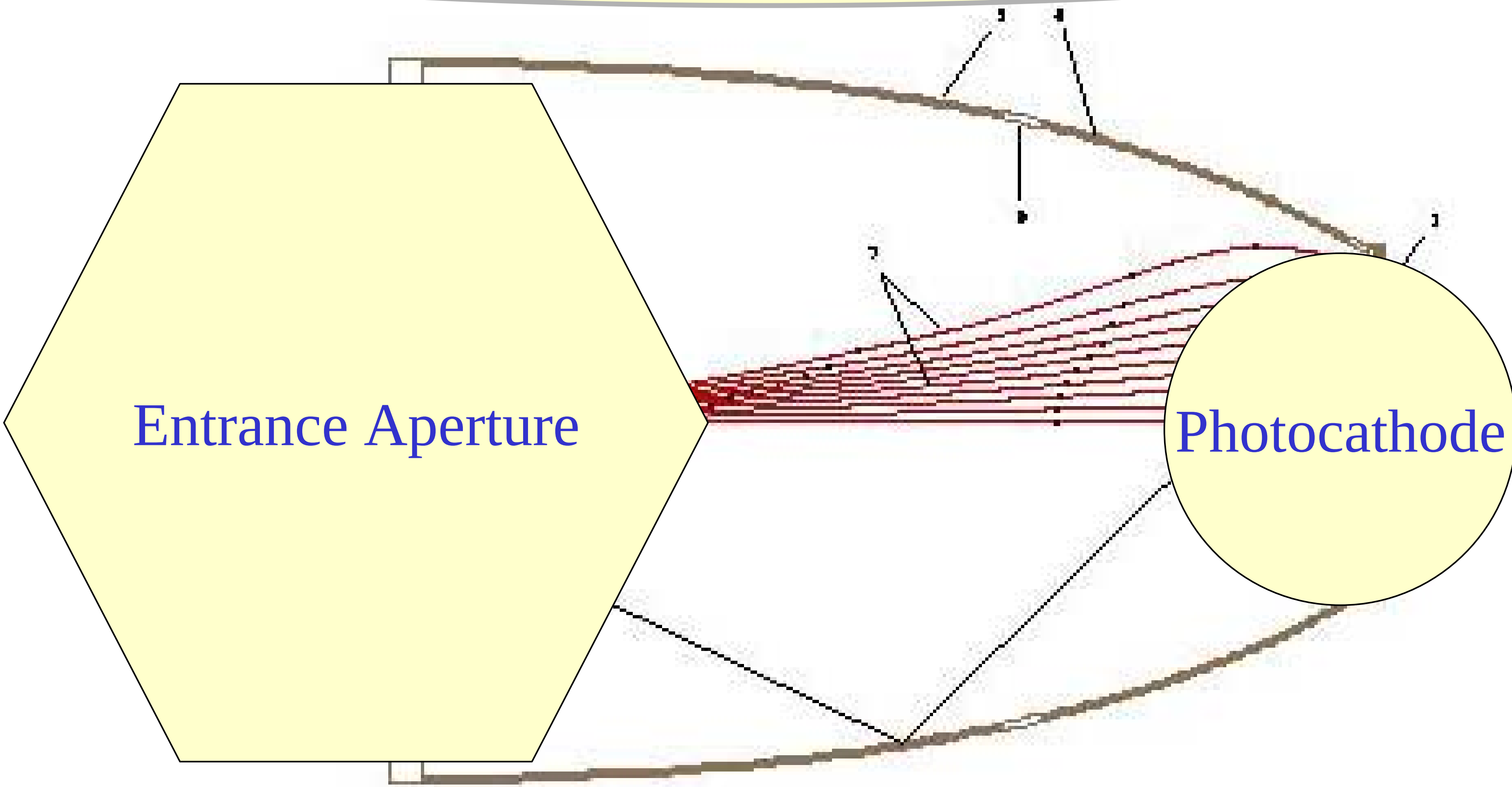


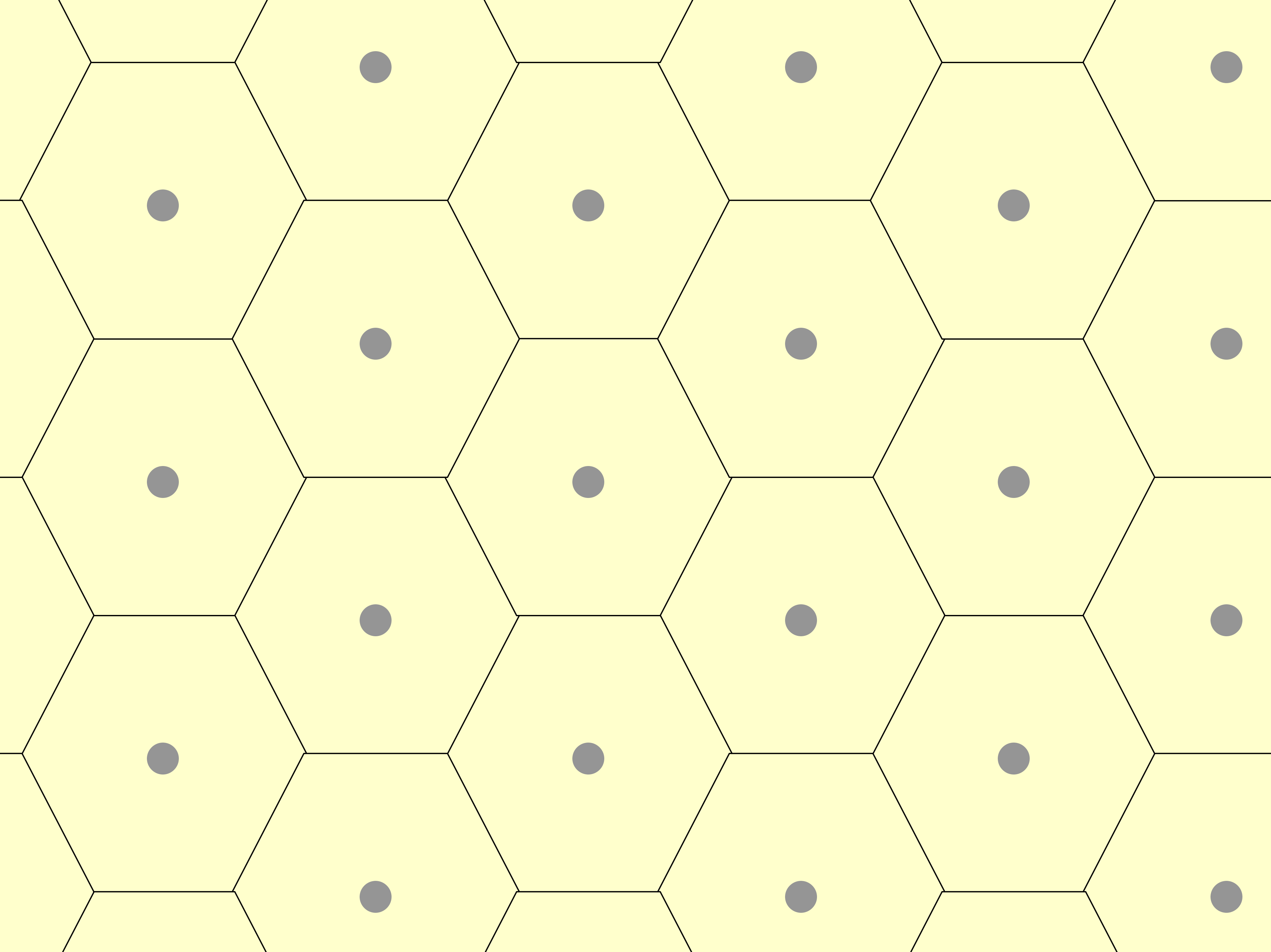
Optimal Electron Lens

Very Important: Hexagonal Packing

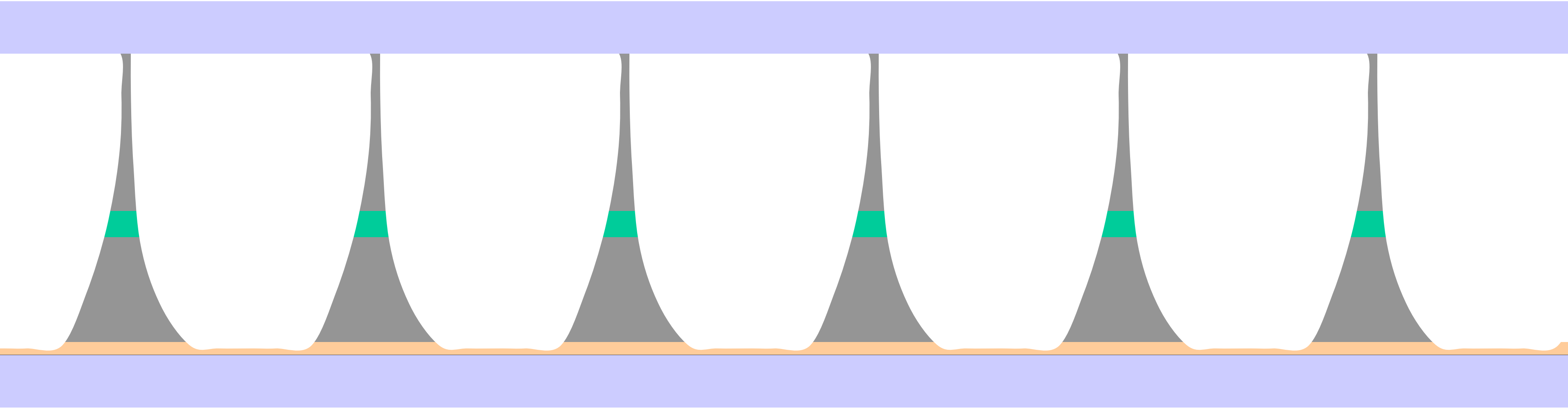


Very Important: Hexagonal Packing





Flat-Panel Honeycomb Sandwich Camera Construction



Industrial Production (no glass blowing etc.)

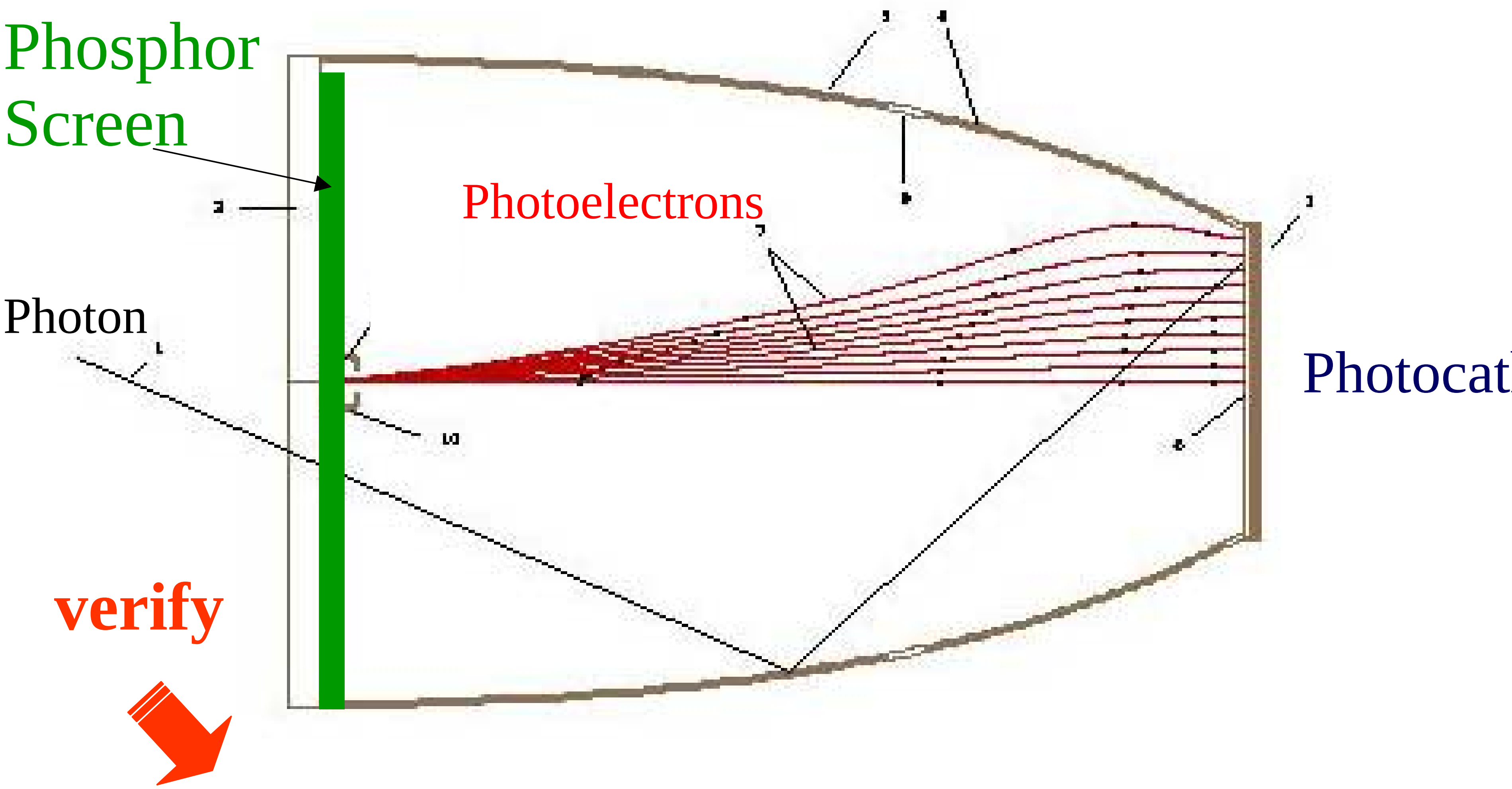
Intrinsic Mechanical Stability, Low Buoyancy,..

ReFerence Prototype

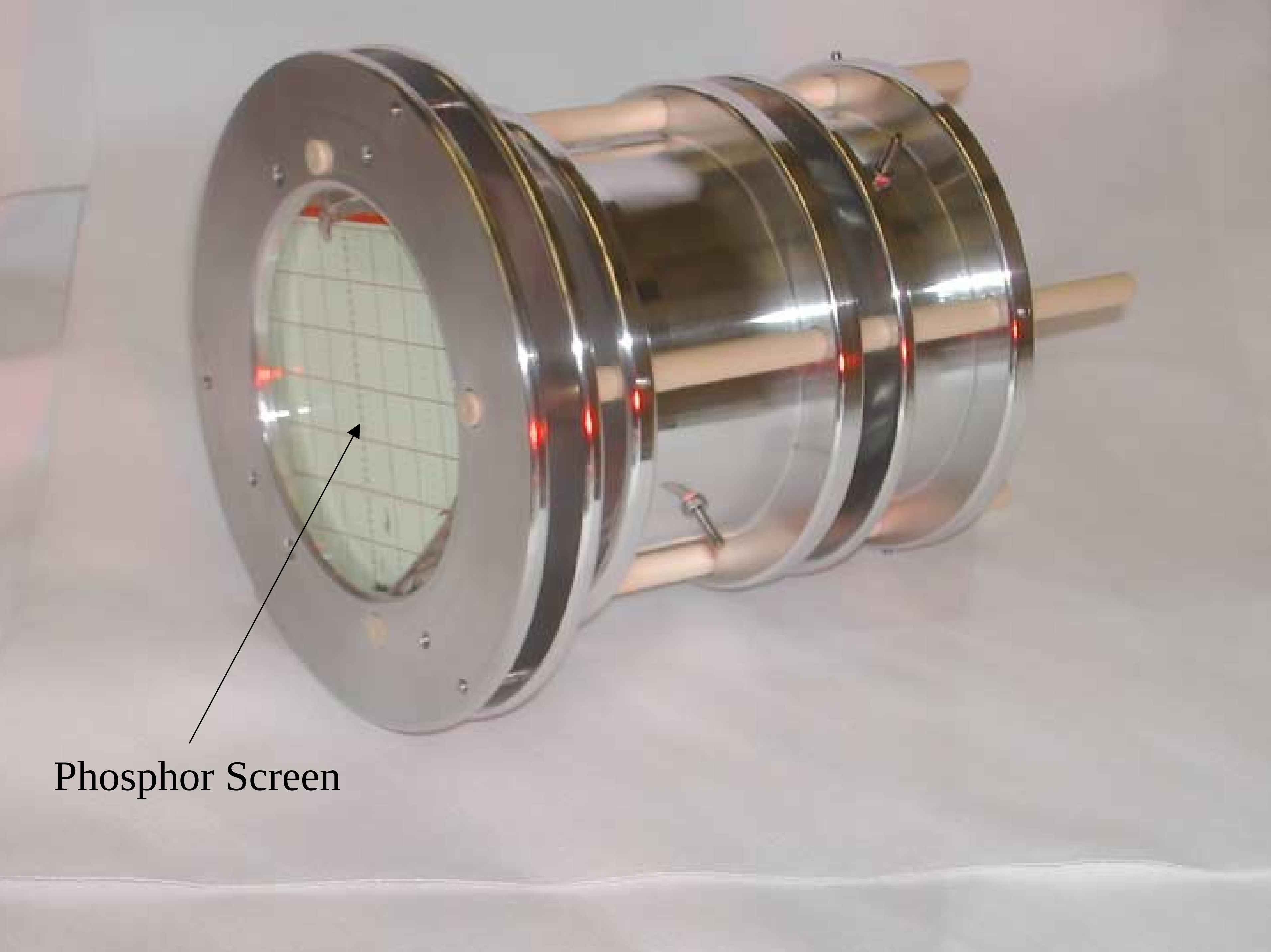
3” diameter, single pixel

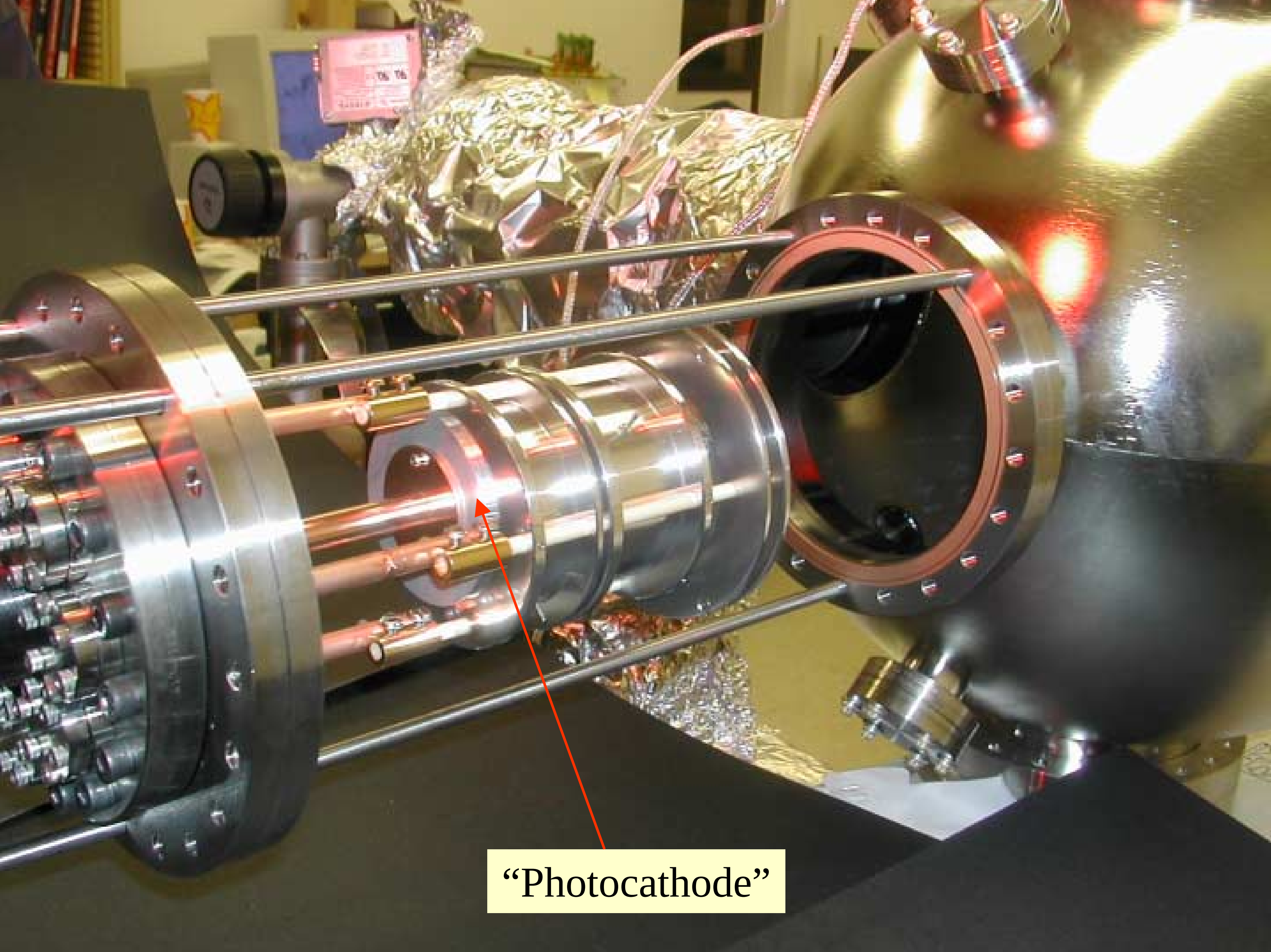
(successfully tested – see below)

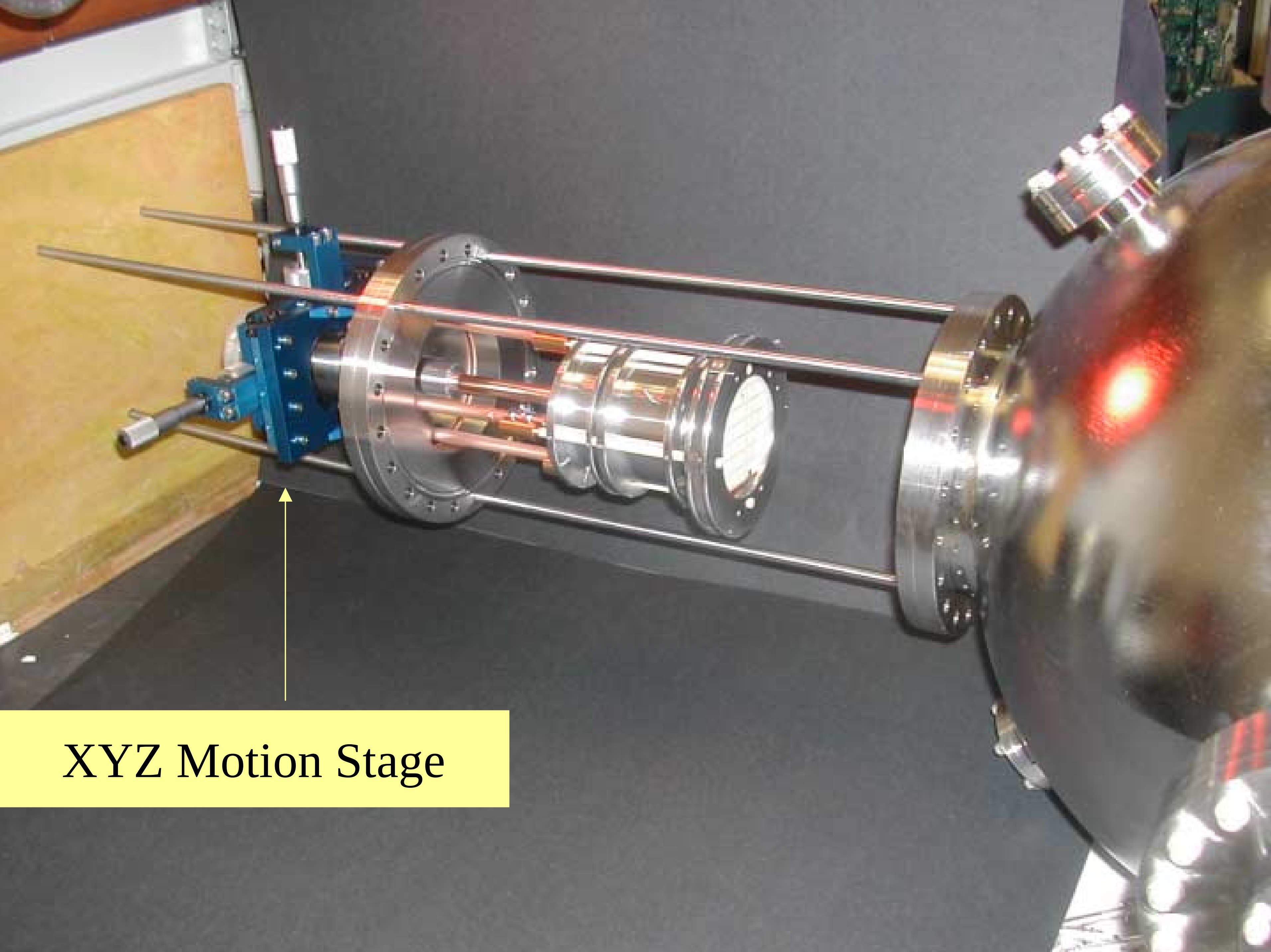
Ideal Light Concentrator = OK!

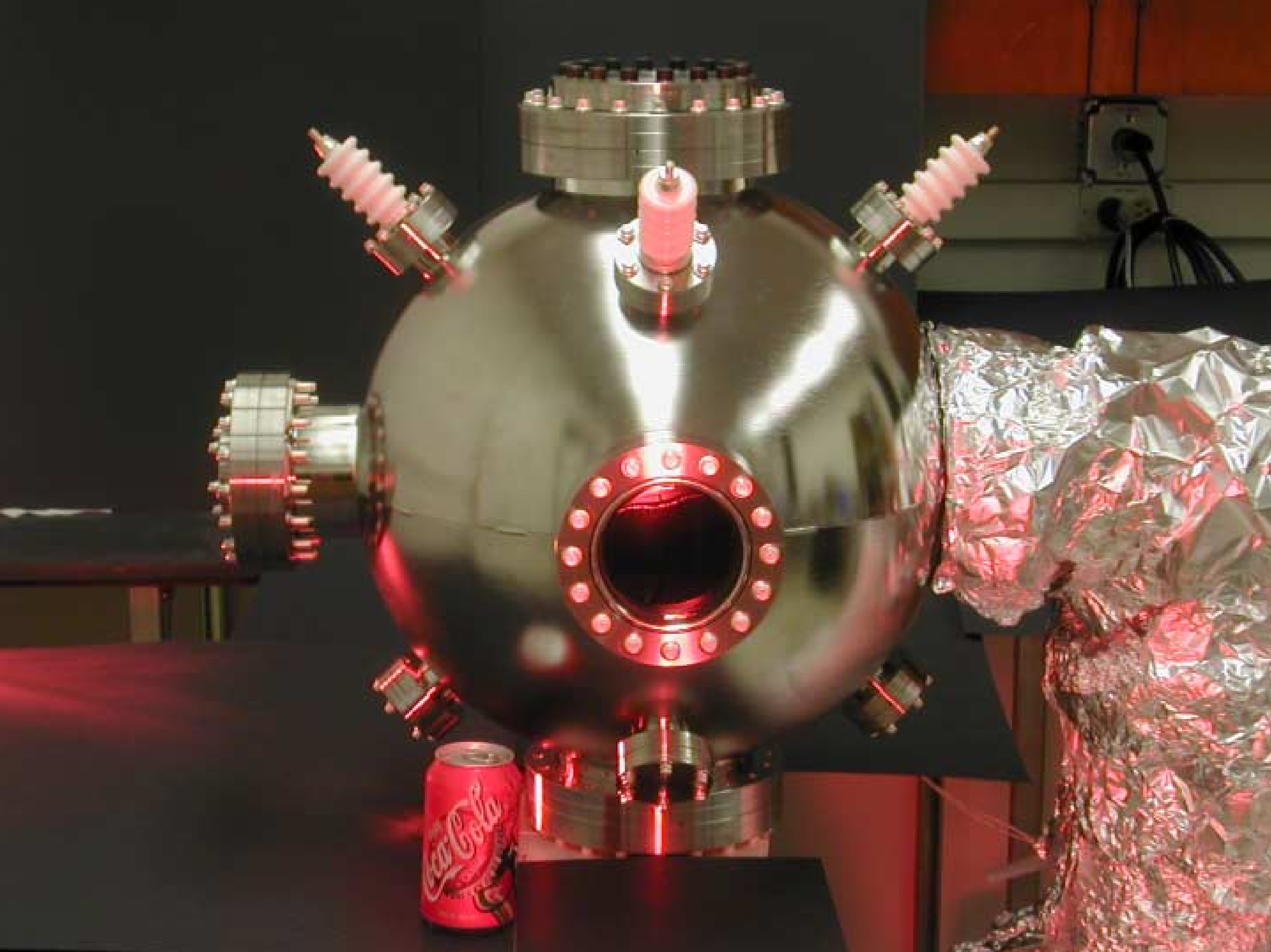


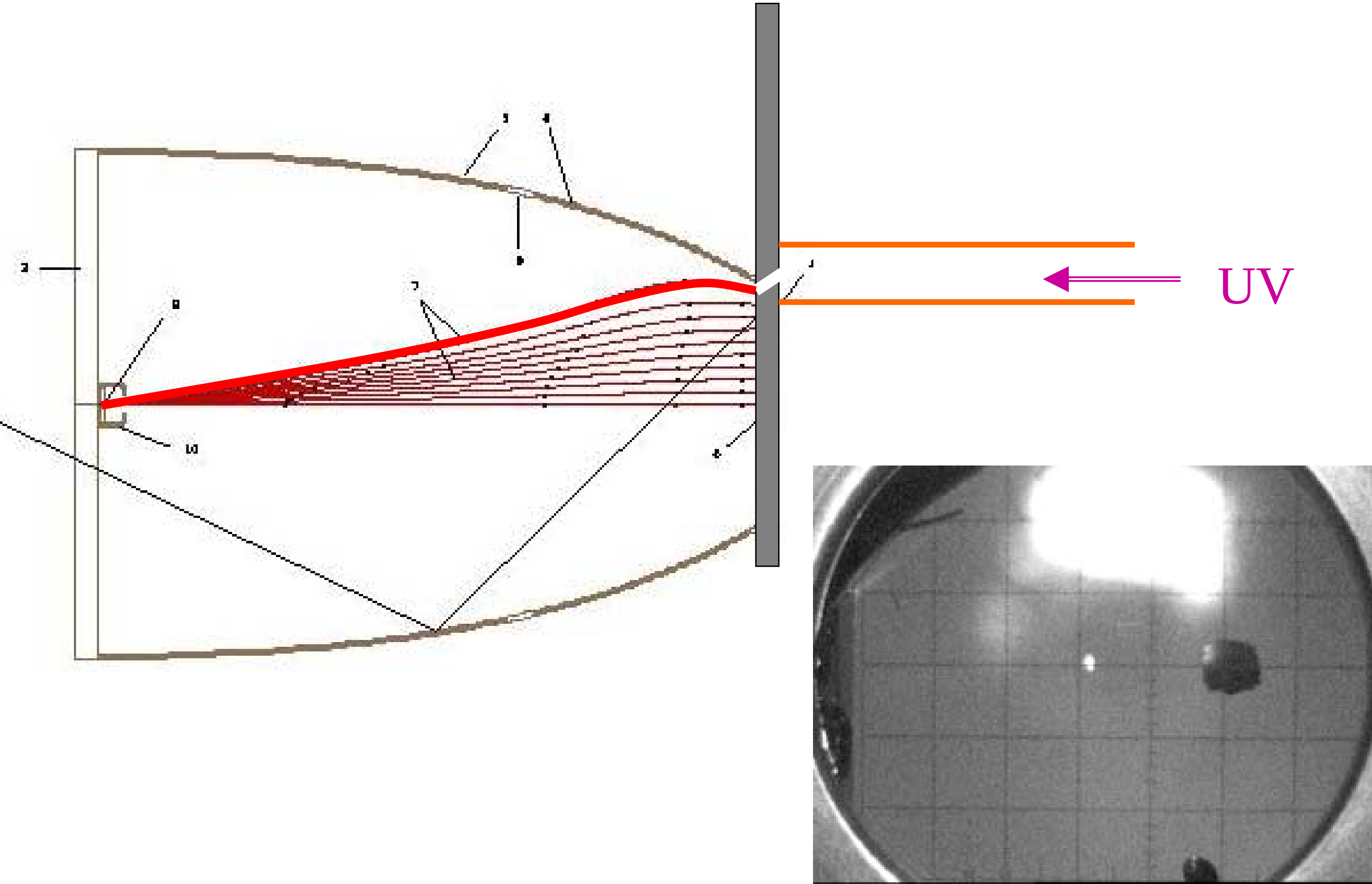
Optimal Electron Lens

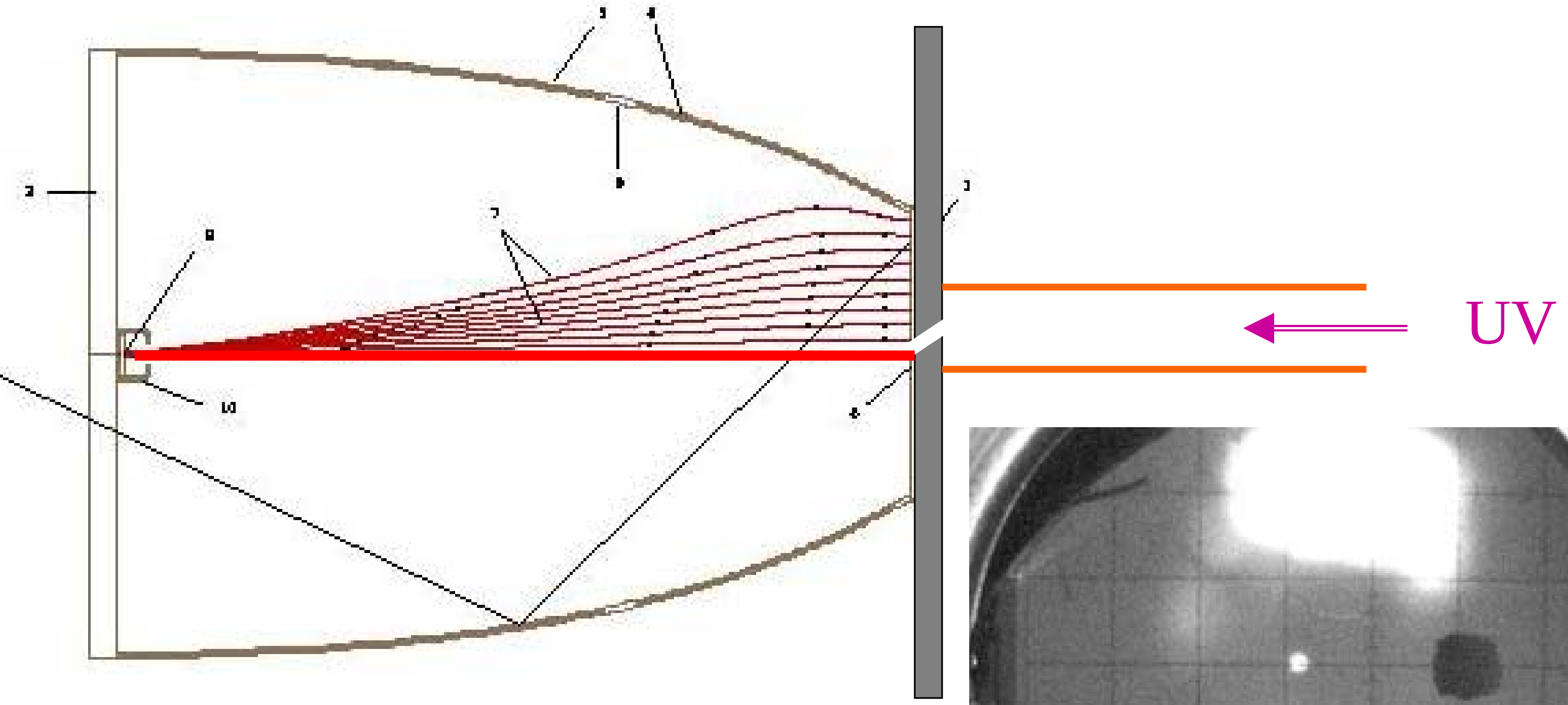

Phosphor Screen

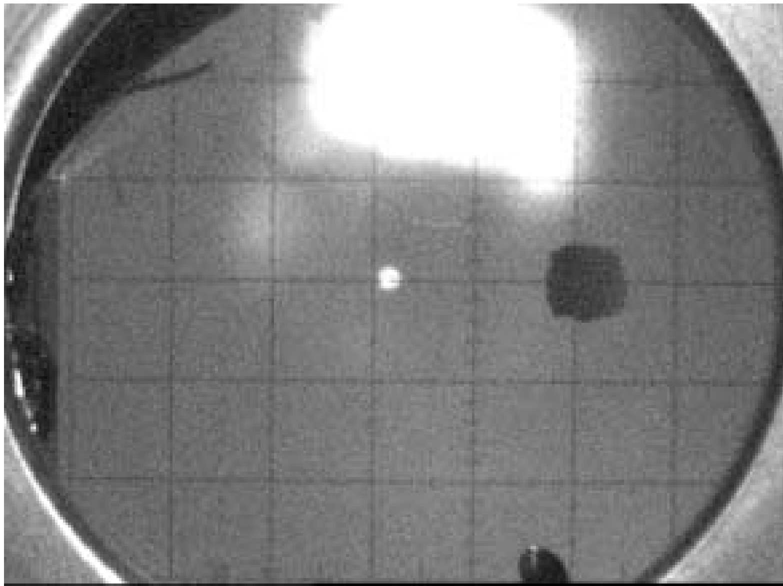

“Photocathode”

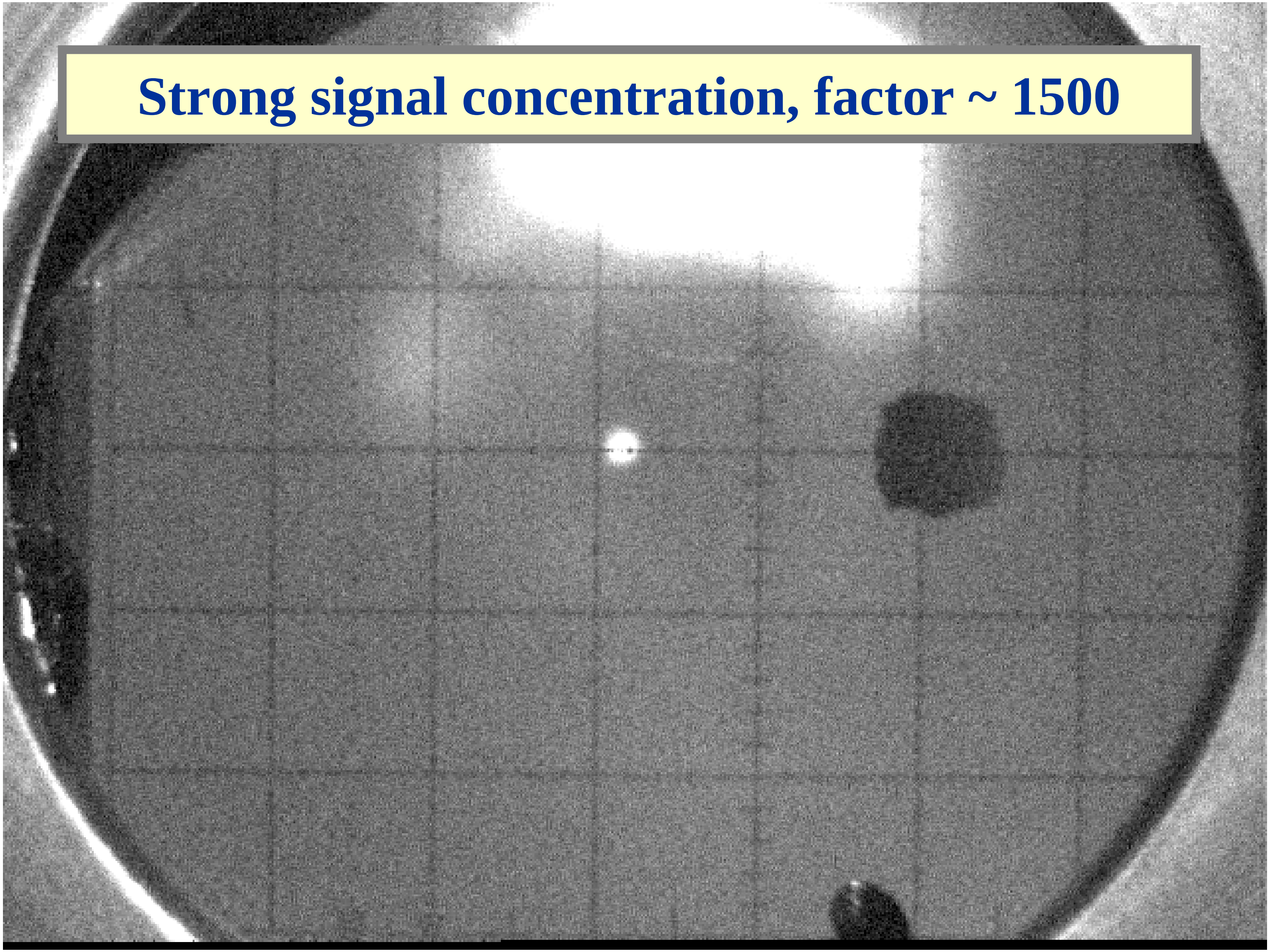

XYZ Motion Stage


Coca-Cola

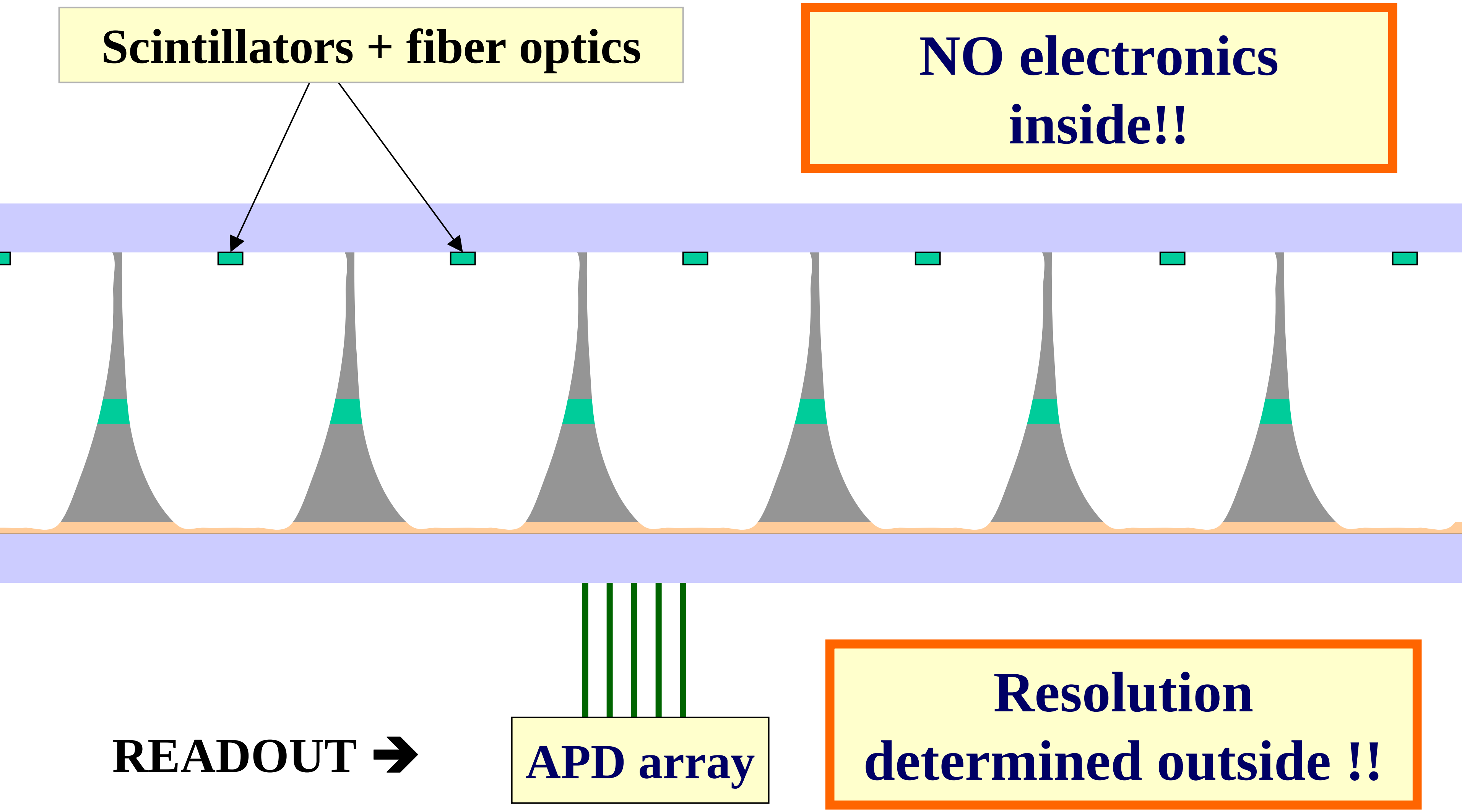

UV


UV




Strong signal concentration, factor ~ 1500

“*Light Amplifier*” Concept



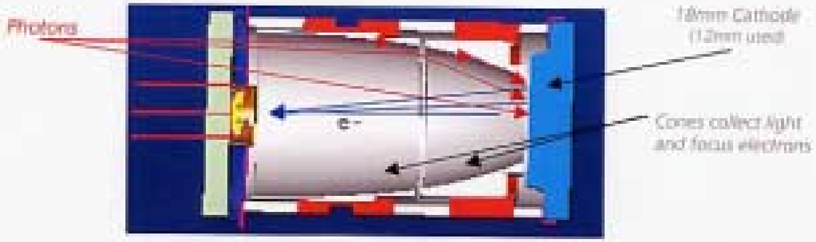
product CONCEPT DATA

Reflection Mode Hybrid Photomultipler Tube (ReFerence Tube)

Program: ITT funded development of a small prototype reflection mode Hybrid PMT using a Compound Parabolic Concentrator (CPC) for light concentration and electron focusing. The use of CPCs instead of lenses greatly improves light gathering and allows for a very precise cut-off on the acceptance angle.

The intent of this program is to produce a high-efficiency, low-time jitter photodetector with high QE from UV to red for use in various applications, including imaging atmospheric Cherenkov telescopes.

The use of a reflection mode cathode in this application will improve QE, particularly in the UV. Dr. Daniel Ference of UC Davis developed this design concept and collaborates with ITT on this development program.



Timeline:

- Program start — Nov/Dec 2001
- First prototypes sealed — April 2002
- Present emerging results at *New Developments in Photodetection*, Beaune, France — June 2002

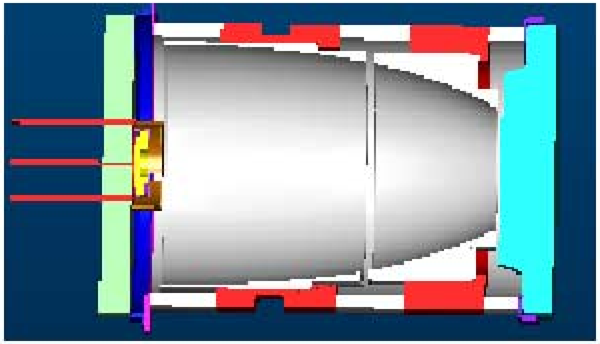
Technical Contact: Rudy Benz
Phone: (540) 563-0371 • email: rudy.benz@itt.com
Business Development Contact: Harry Montoro
Phone: (540) 362-7375 • email: harry.montoro@itt.com

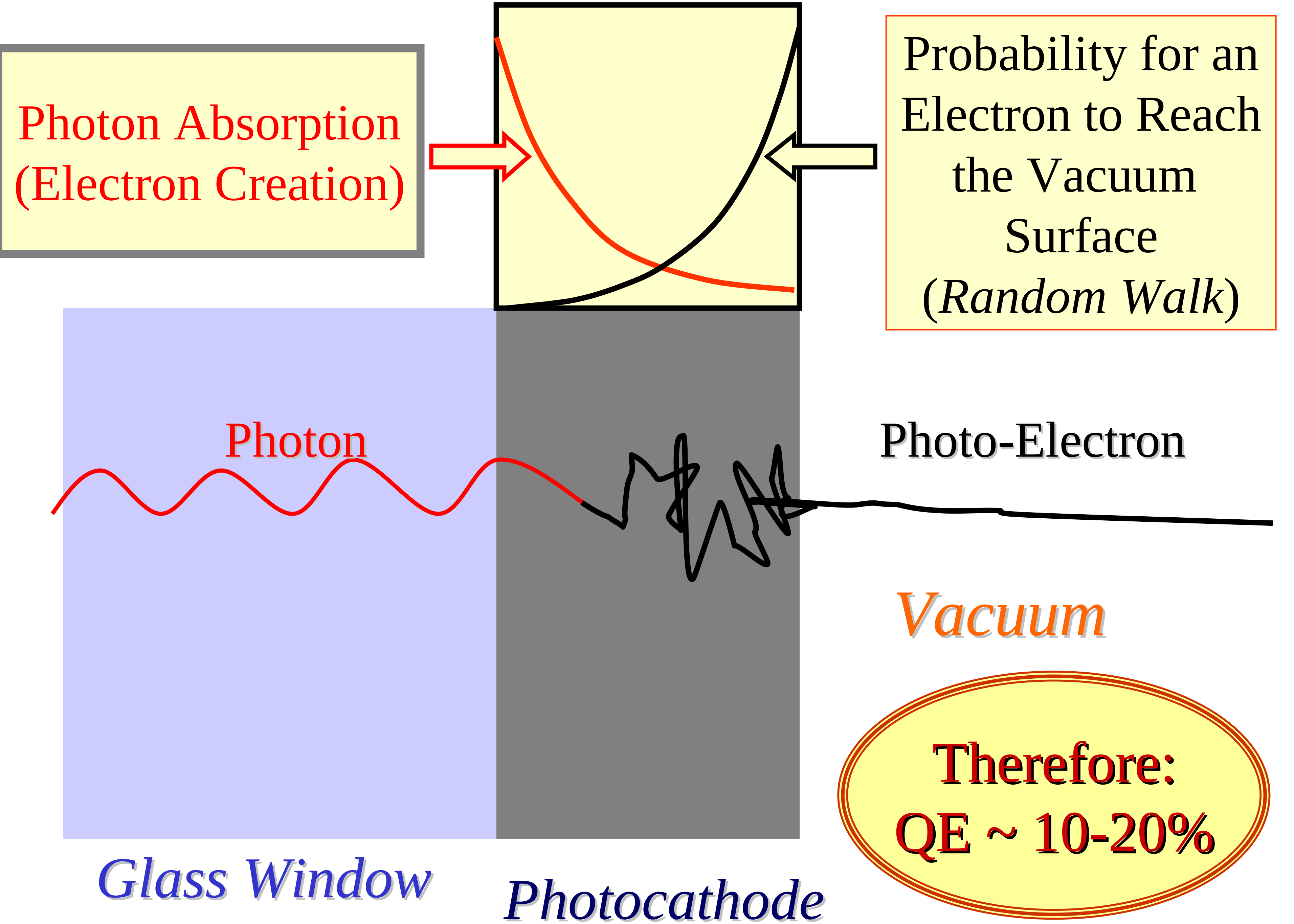
ITT Industries Night Vision
7635 Plantation Road
Roanoke, Virginia 24019
www.nightvision.com

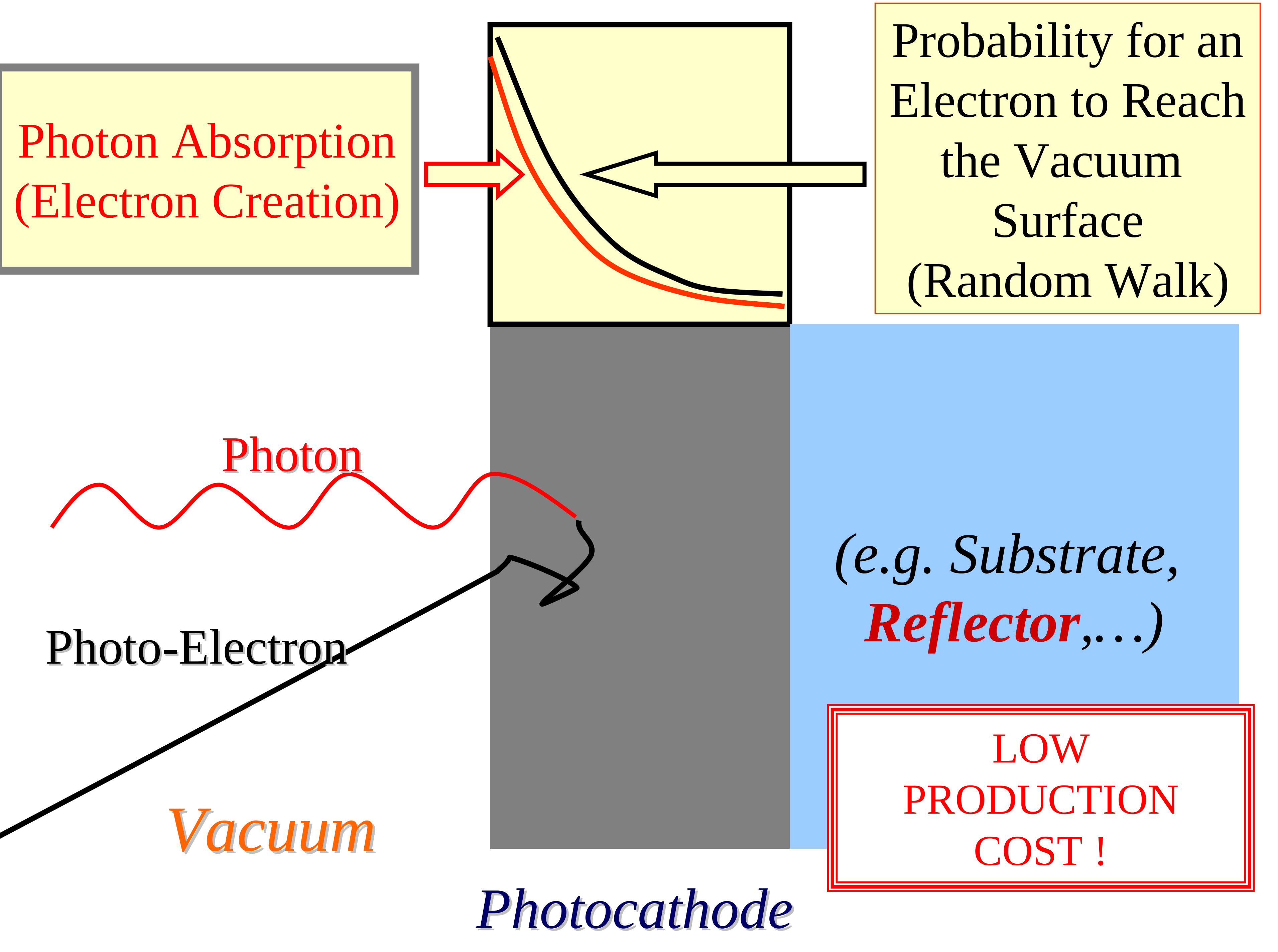
ITT Industries
Engineered for life

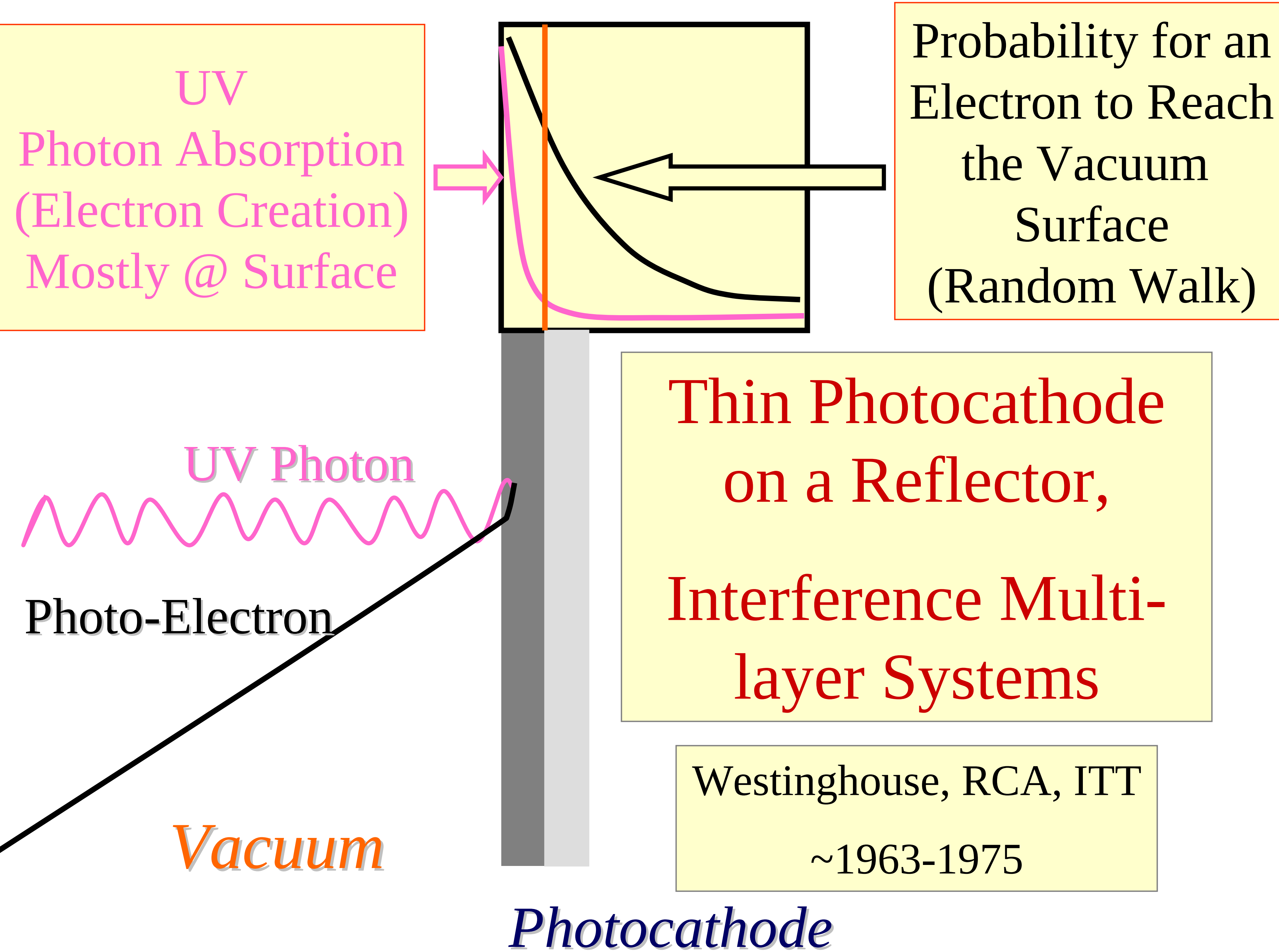
ReFerence Tube Design

- Reflection mode GaAs cathode (12.5mm used)
- Sapphire input window 25mm aperture
- High voltage APD (API)
- Segmented Kovar CPCs for concentration and timing
- Size chosen to use standard parts and tooling
- Prototype device to test design concept with short time and internal funding
- Anticipate improved external QE 300-400nm and good QE out to 900nm

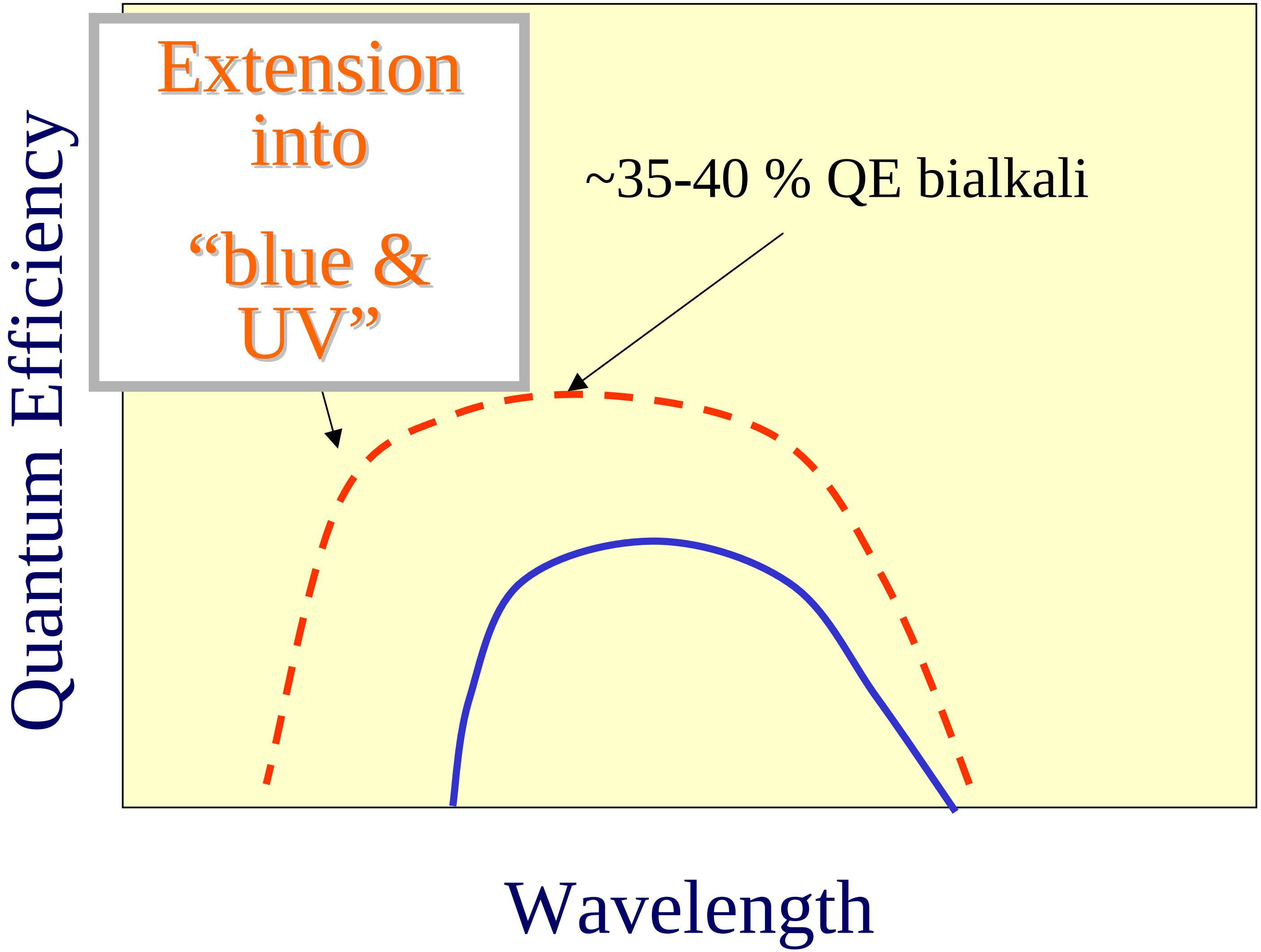


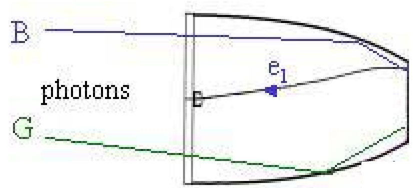

Photon Absorption
(Electron Creation)
Probability for an Electron to Reach the Vacuum Surface
(Random Walk)
Photon
Photo-Electron
Vacuum
Therefore:
QE ~ 10-20%
Glass Window
Photocathode


Photon Absorption
(Electron Creation)
Probability for an Electron to Reach the Vacuum Surface
(Random Walk)
Photon
Photo-Electron
(e.g. Substrate, Reflector,…)
LOW PRODUCTION COST !
Vacuum
Photocathode


UV
Photon Absorption
(Electron Creation)
Mostly @ Surface
Probability for an
Electron to Reach
the Vacuum
Surface
(Random Walk)
Thin Photocathode
on a Reflector,
Interference Multi-
layer Systems
UV Photon
Photo-Electron
Vacuum
Westinghouse, RCA, ITT
~1963-1975
Photocathode

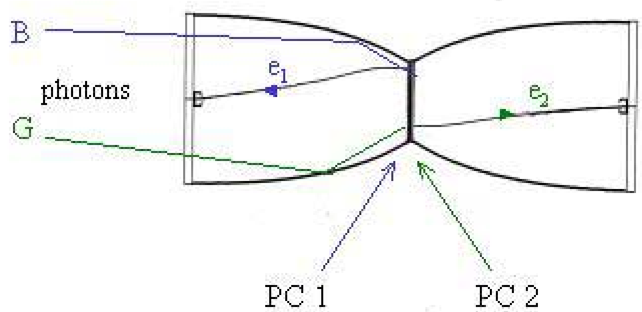
Reflection Mode vs. Transmission Mode





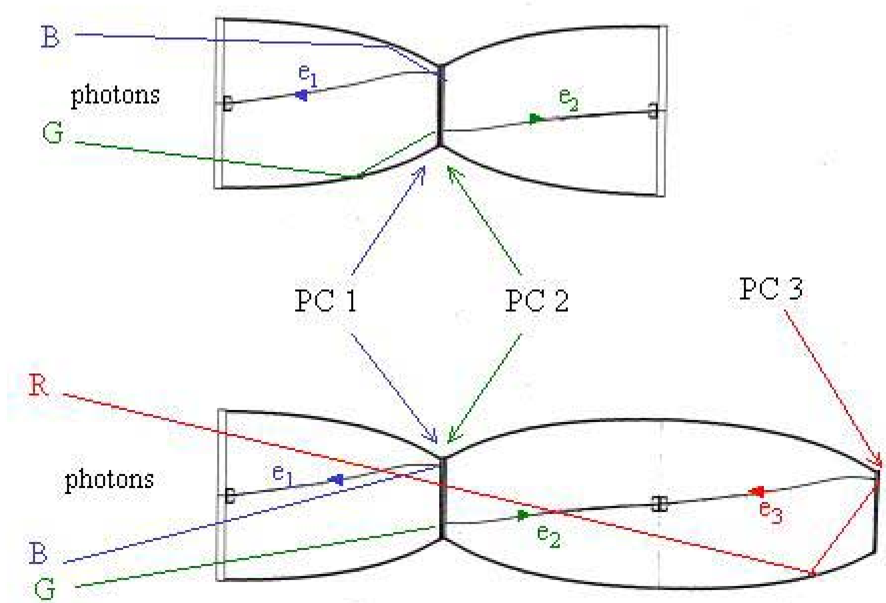
B
photons
G
e_1

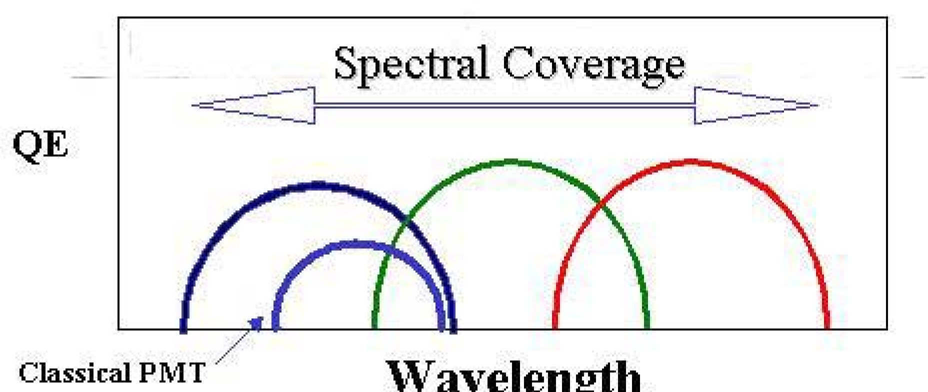
Single-Photon Color Sensitivity



TransReFerence

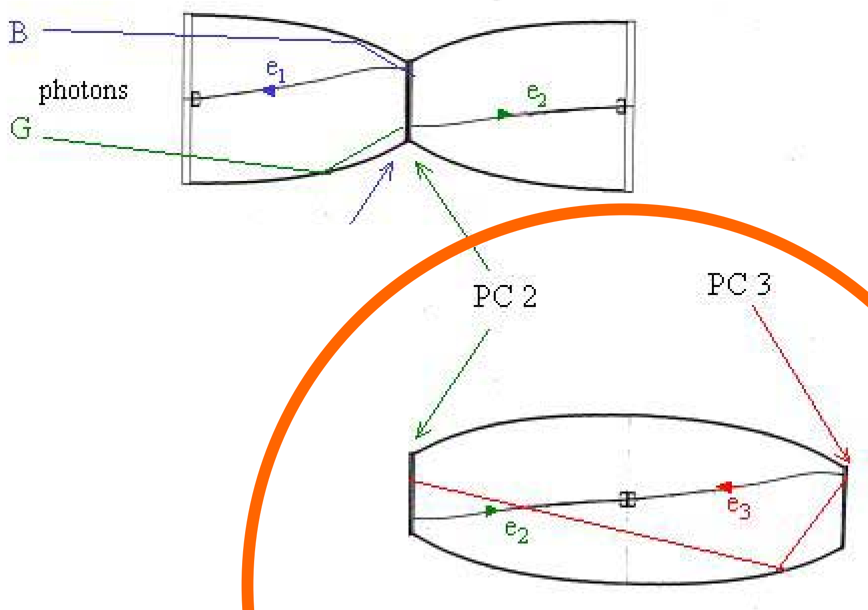
Single-Photon Color Sensitivity





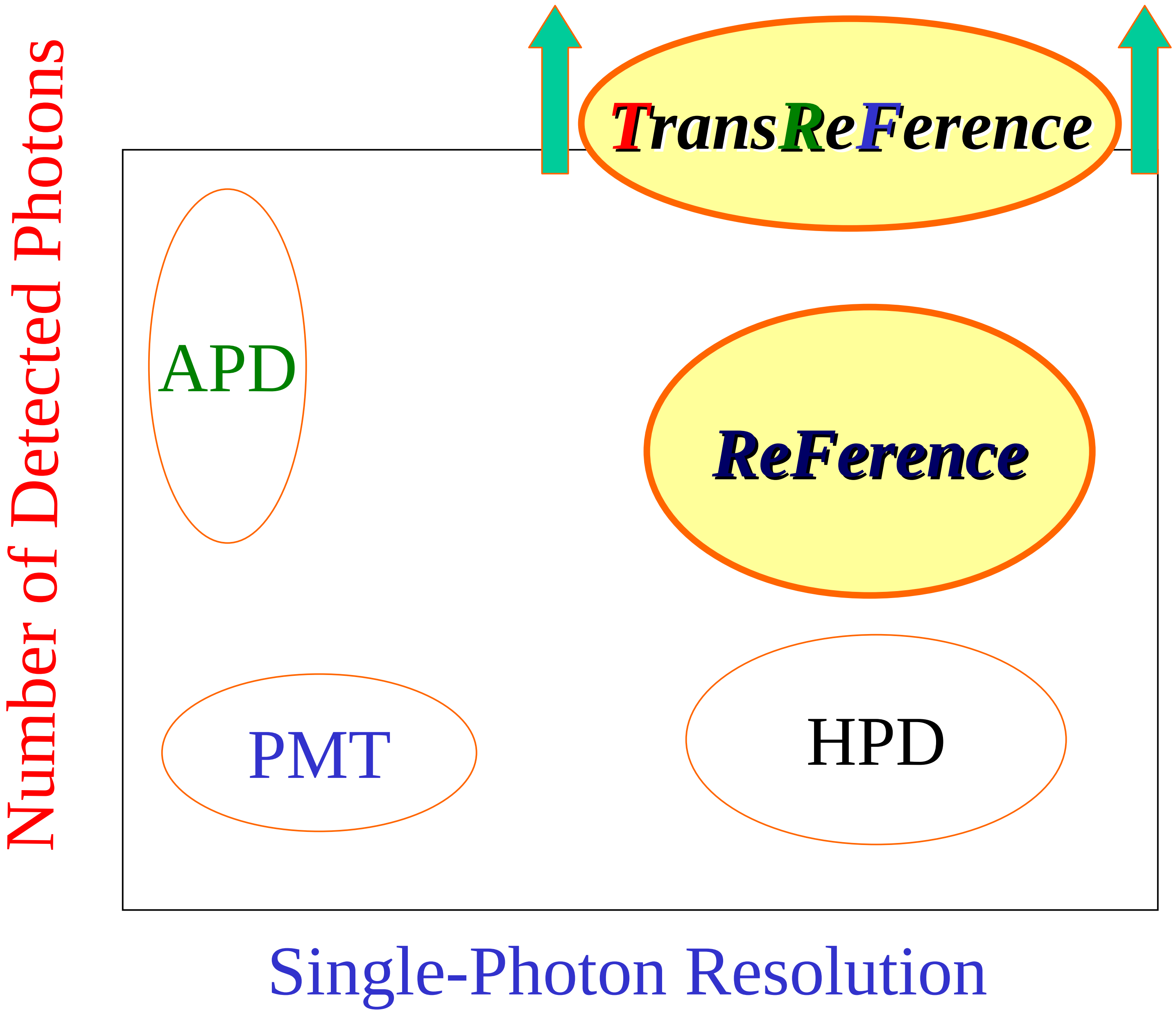
TransReFerence

Single-Photon Color Sensitivity

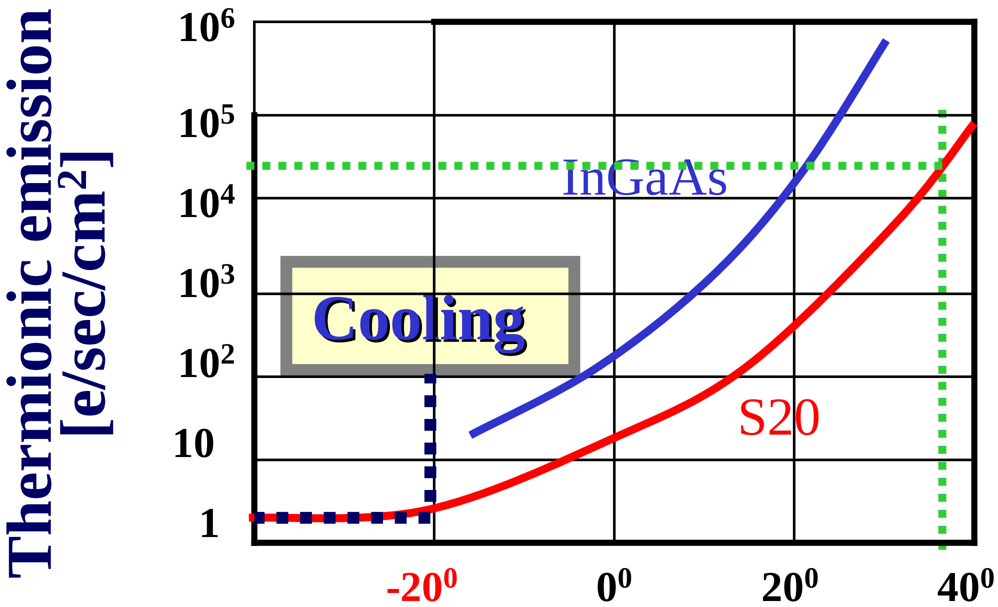


Transmission-Reflection

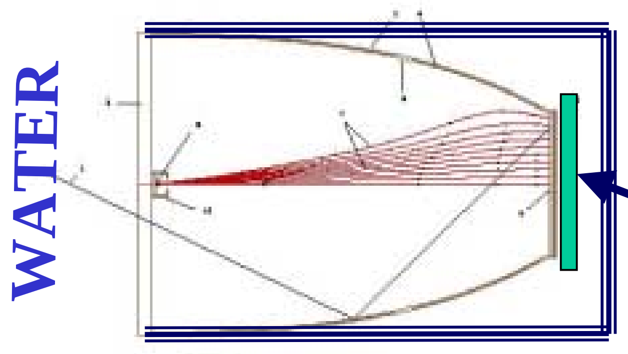
(and also light trap)


TransReFerence
ReFerence
APD
PMT
HPD
Number of Detected Photons
Single-Photon Resolution

Photocathode Cooling - Diminished Dark Current

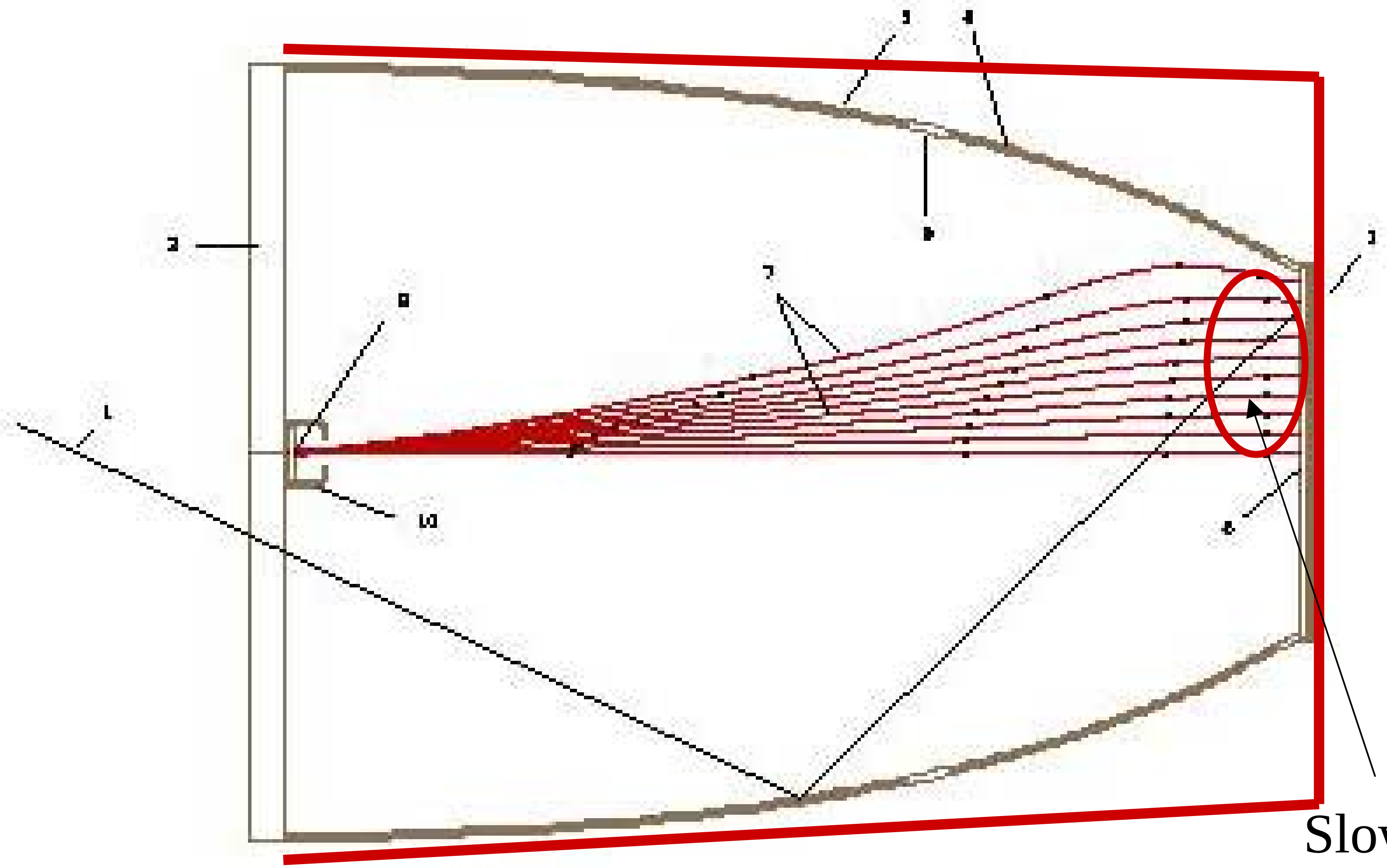


Carlsbad NM



Cooling (Peltier)

VERY EFFICIENT MAGNETIC SHIELDING



e.g. UNO with Magnetic Field (???)

WHAT WE HAVE @ UC Davis

- **Ideas, enthusiasm, physicists**
- **Running Projects**
- **Equipment (>$2M value)**

For Photocathode development, surface science:

Surface Science laboratory: AES, XPE, SIMS,…

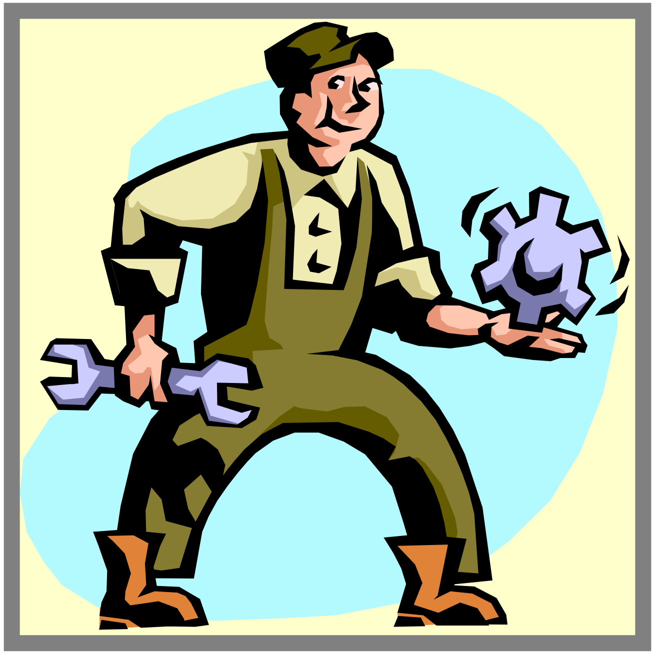
For Flat Panel <u>manufacturing</u>:

2 Flat Panel Sealing Devices (IR Laser Sealing)

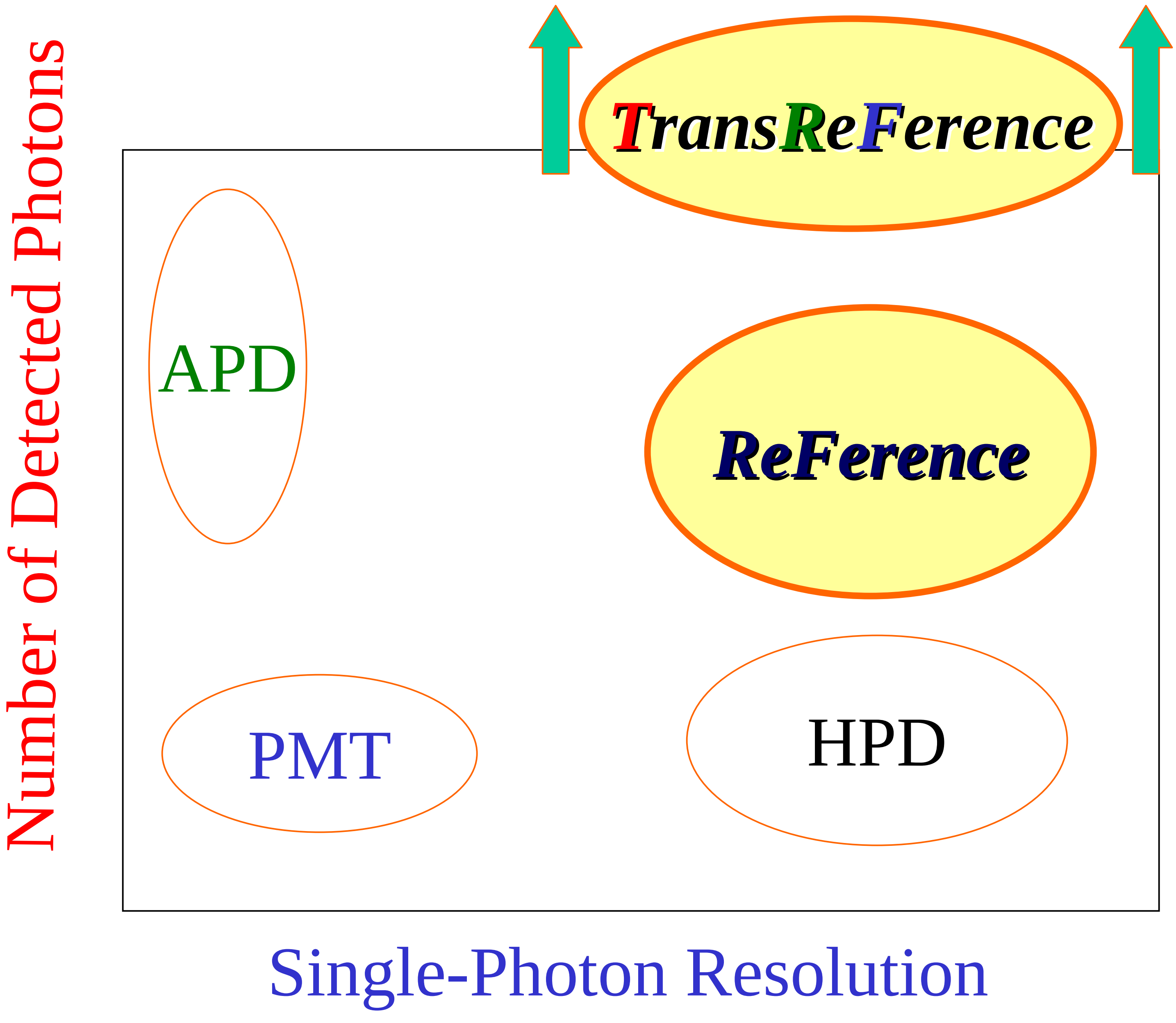
Several Transfer Systems !!!

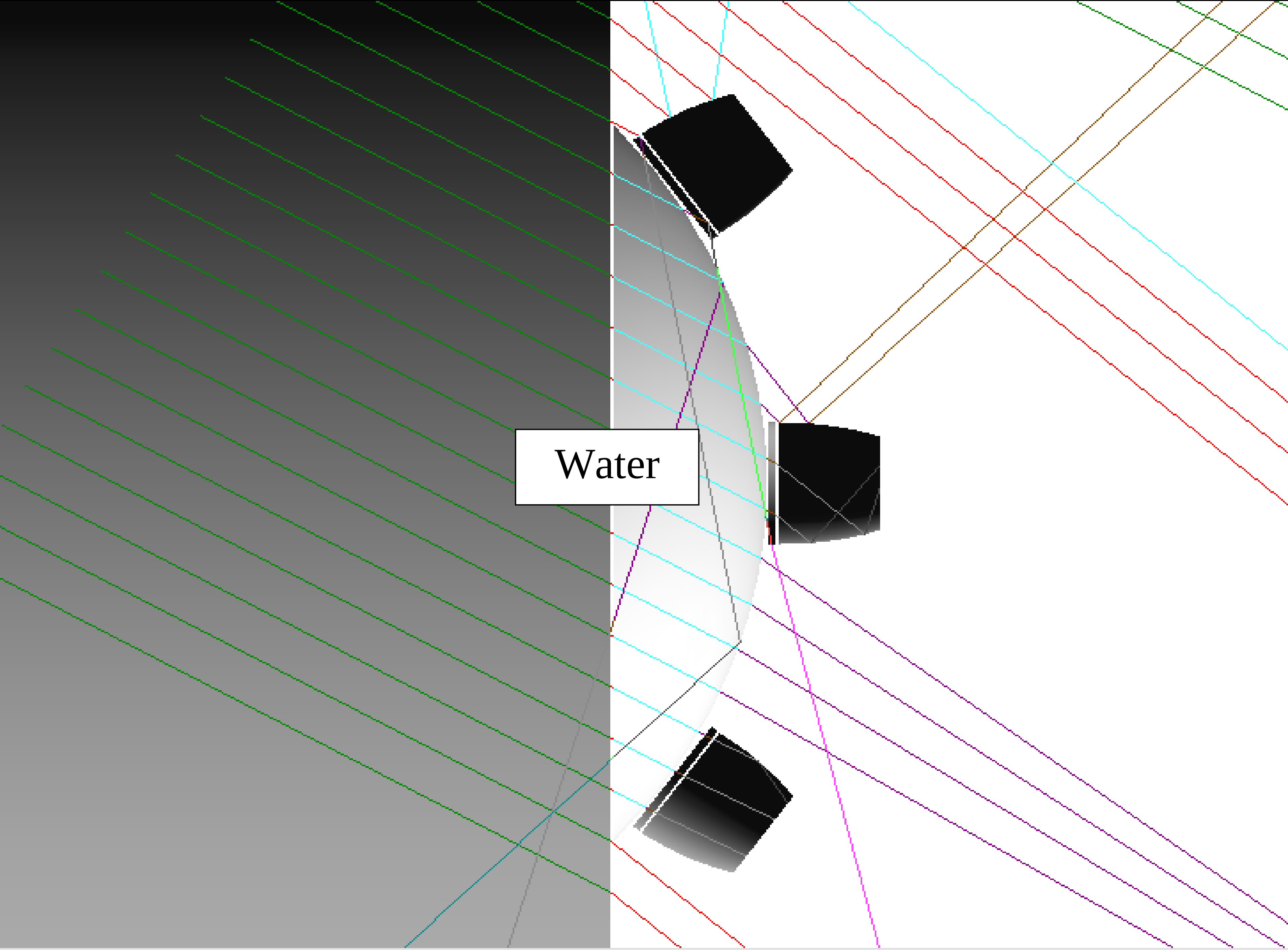
Laser Sealing System (2)

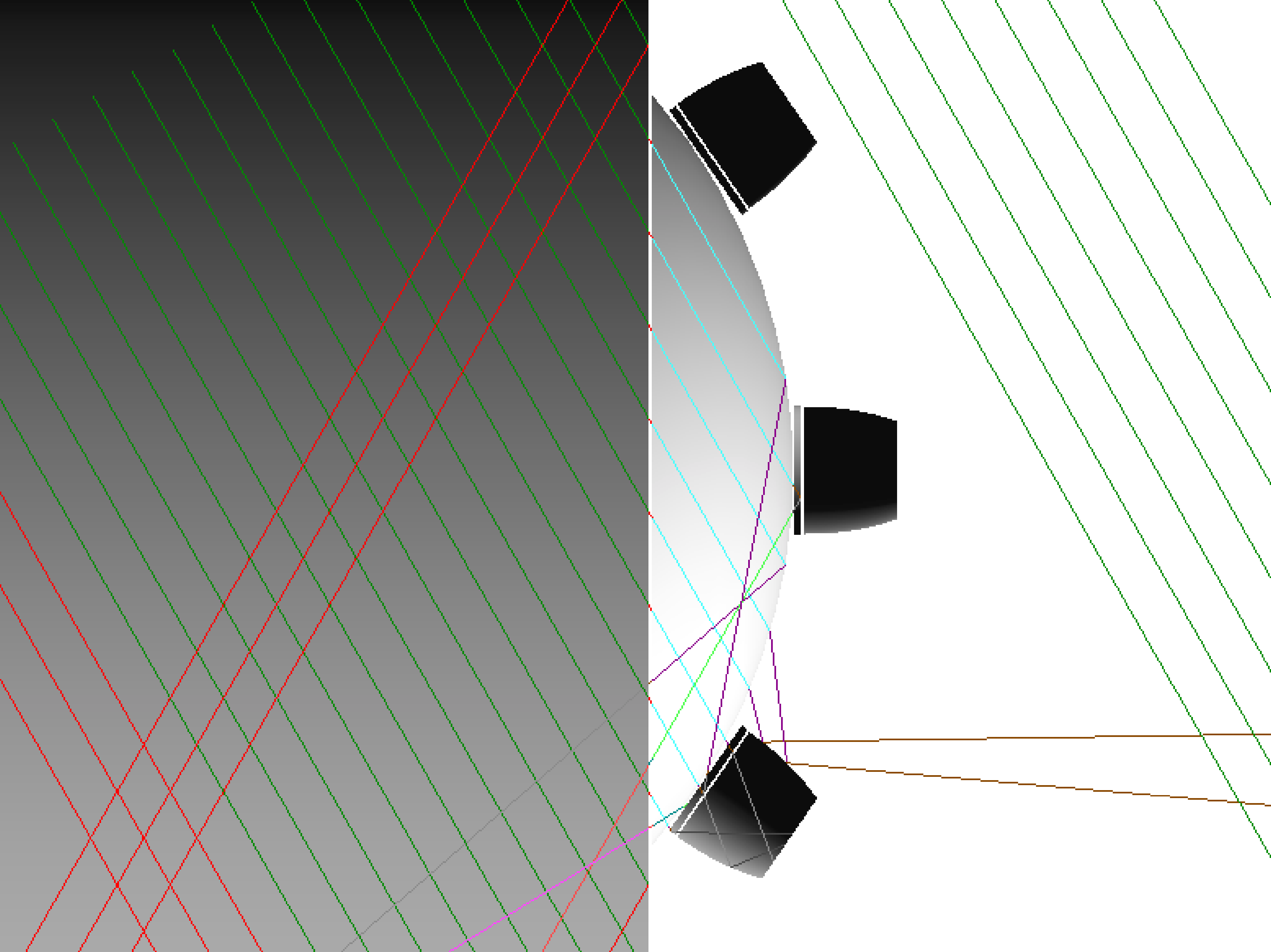
WHAT WE NEED:

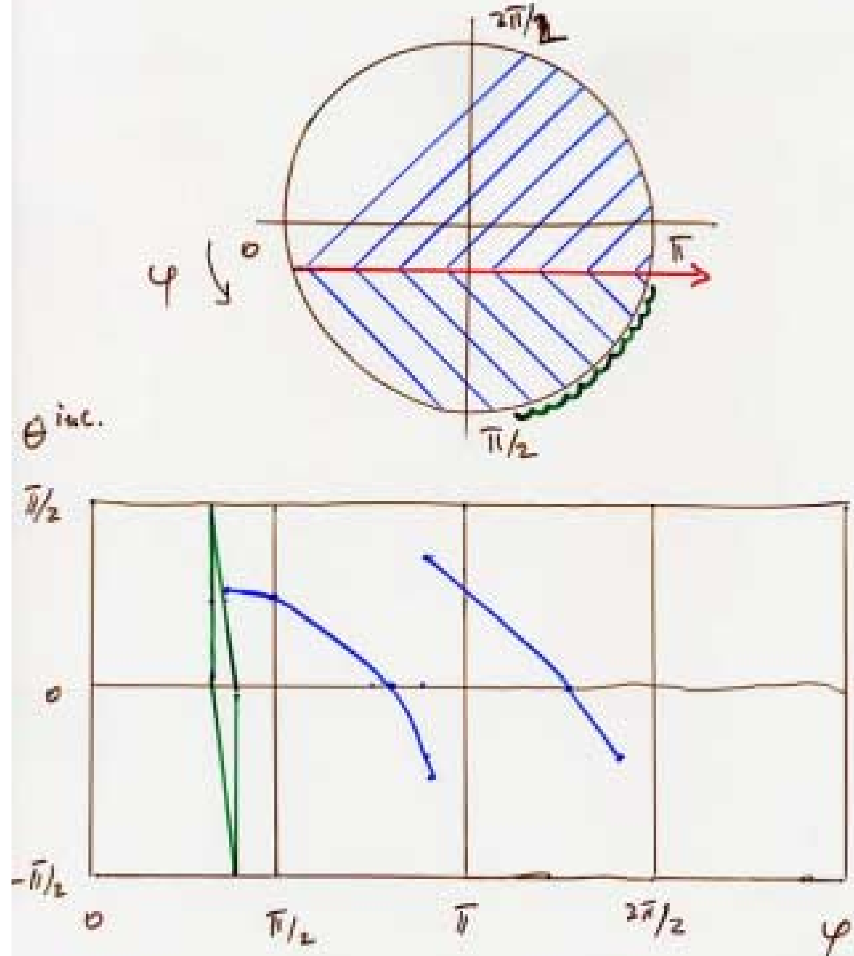


AND THEN → NEW PHYSICS

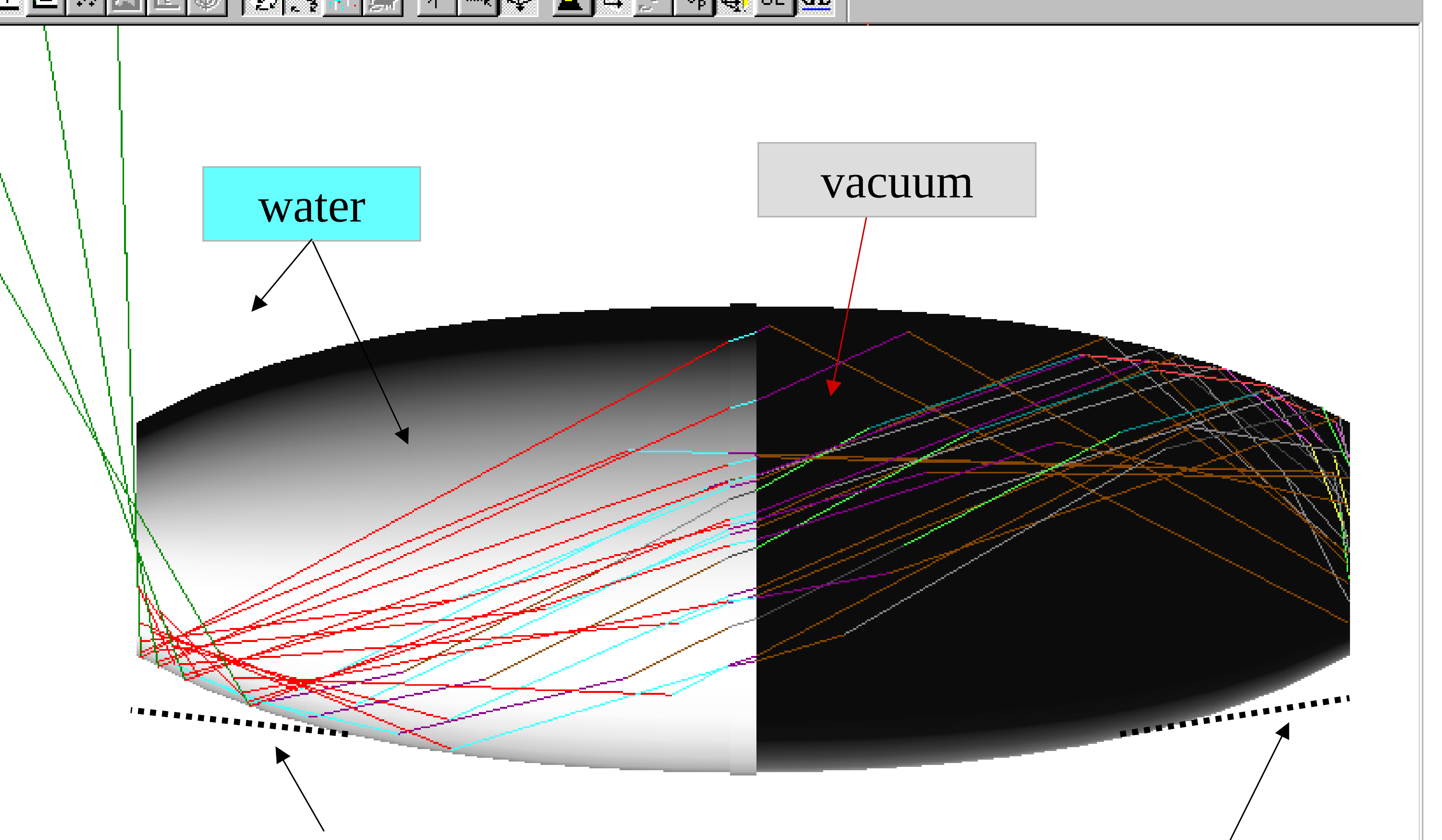

TransReFerence
APD
ReFerence
PMT
HPD
Number of Detected Photons
Single-Photon Resolution


Water





SPHERICAL MULTIANGULAR RECORDING
TRACKER
"SMART"



If Larger Acceptance Angle is Needed